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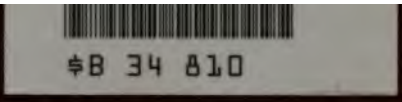
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In the background are the arêtes of Snowdon; the wall between the upper and lower cirques lies below, with the great *roche moutonnée* in the centre of the lower cirque. Moraine-blocks strew the foreground.

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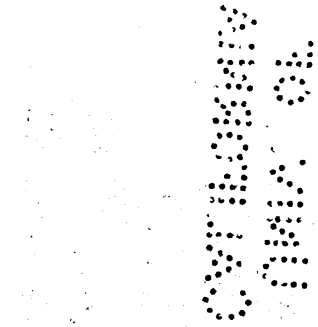

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TO

ARTHUR JACKSON

THE SECOND EDITION OF THIS BOOK

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PREFACE TO THE SECOND EDITION.

In 1895, in the preface to the first edition of this little book, I sought to excuse its imperfect mode of treatment of a wide and impressive subject. Some slight knowledge of chemistry and physics may happily be presupposed; and the first chapter is chiefly intended as a reminder of what may be learnt in school. The main part of the book, however, is addressed to those who are willing to look out upon the world, to those who spend their summer holidays in walking, or cycling, or travelling in any sense from home; and it is hoped that the details given of certain special districts may be applied to places immediately familiar to the reader. Nowadays, when journeys by road have become more than ever possible, the geography and geology of nearer Europe are keen realities to many of us; and, at the risk of incompleteness, I have dwelt as far as possible on things that I have personally seen.

But it is one thing to see and to enjoy, and another to seek for an explanation. Hence references have been given to the work of those who have patiently set us on the proper path. The wider our view of what others have done, the more we recognise that science owns no country, and that in every land we find our colleagues and our friends. In this spirit, moreover, metric and English measures have been wilfully mixed throughout the book, especially as Continental maps are based upon the refined and rational metric system. Such maps form the best illustrations to many of the descriptions in the text.

In this edition a few new pictures have been added, and it would be tempting to increase them largely; but the intent, after all, is to urge the reader to see for himself how "the mountain falling fadeth away, and the rock is removed out of its place; the waters wear the stones; the overflowings thereof wash away the dust of the earth." As was

said in our former preface, "the great aim of this little book is to keep in view the fact that geology, like true zoology and true botany, is a study of the open air. To dissect a rabbit in the laboratory is a more intellectual exercise than to shoot him as he runs across the sand-hills; but the object of such study, after all, is the understanding of the rabbit when alive. The average sportsman, with a careful eye for the habits of an animal, may at times go nearer towards this end than the average student at his microscope; and, similarly, it is only by a combination of two types of observation that a sound geologist can be made. Almost all great progress in natural knowledge has thus been made by those who have seen and travelled, by those, in fact, who have studied in Nature's roofless school."

And let me again thank those whose names appear in connection with the illustrations, and not only these, but Mr. G. W. Lamplugh, Mr. E. P. Ridley, Mr. Henry Preston, and others who have helped me, including various correspondents and the publishers of *Nature*. The view of Rockall, now added on p. 120, has special interest, seeing how very rarely this isolated relic has been seen by scientific observers. Mr. Welch's photographs, displaying both geological and artistic judgment, add very greatly to any interest that the volume may possess; and it has been pleasant to include two from my Father's series, which formed my introduction to geology out-of-doors more than thirty years ago. It is hoped, in conclusion, that the various changes in the text may help to bring these open-air studies abreast of our present knowledge.

GRENVILLE A. J. COLE.

DUBLIN, *July*, 1902.

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OPEN-AIR STUDIES

CHAPTER I

THE MATERIALS OF THE EARTH

WHEN we were children, as soon as we could think and ask questions, most of us tried to find out two important matters—how to make things, and what things are made of. The little boy who cut open his drum to see where the sound came from was not so entirely foolish as is sometimes represented, for he at least made an interesting and valuable experiment. He learnt in this way that a drum was best constructed by stretching two thin skins opposite to one another, and shutting in a quantity of air between them. He was not satisfied with the mere showy outsides of things, or with the royal arms of Great Britain and Ireland painted on the wooden barrel of the drum. He felt that the sound, which was the great feature of the instrument, must have a cause; and he set to work to find out something about it for himself. Probably he only got as far as seeing how the drum was made, and had to ask his father for the reason of this particular arrangement. But that is what every one has to do, and why no great discovery is likely to be of use to us unless we know what other people have previously discovered. In the same way, we cannot write a passably useful book unless we are near the 50,000 volumes of a well-stocked public library. Our knowledge in this world does not go on by jumps and bounds, but by a study of what others have seen and done, and of the records of their failure or success. Even if, after a long series of experiments, we have to leave our old drums damaged and cut open, we may soon have wit enough to make newer and better ones for the service of ourselves and our descendants.

In early times, it was most important that man should find out how to make things. He had to build shelters against the rain; he had to find weapons with which to combat the wild beasts; he had to carve out gourds into vessels in which liquids could be carried. But all these things were by no means easy, and required a good deal of observation. Nature was already doing many wonderful things in the great world round about, and it was well to watch, and even to imitate, these closely. After all, whatever was required by man had to be made out of natural materials. One result of this struggle with difficulties was that early man took to studying the stones beneath his feet. Some of his earliest instruments were made of stone; and we know that many savage tribes have only given up the use of stone axes and stone arrow-heads since the arrival of European traders on their coasts. Primitive peoples would soon observe that some kinds of stone break more easily than others, that some kinds can be chipped in almost any direction so as to give a sharp cutting edge, and that some, again, are far superior in hardness or durability to the rest. It became important to search among the rocks for materials suited to each special purpose; and thus began, perhaps, the first researches into the structure of the world around us.

When native metals were discovered, and when, moreover, it was found that valuable substances could be extracted by heat from stones utterly unlike them in appearance, the study of the earth became a much more complicated matter; and at last a few thoughtful persons took to enquiring how such-and-such materials, used by man in the manufacture of common things, came themselves to be made in the heart of the old solid earth. Then began the science of **Geology**, the systematic study of the way in which the world is built up, and of the natural changes which go on within it and upon it.

Even the earliest men must have seen that the earth changed around them. Floods came down, and covered smiling landscapes with sand and stones from distant hills; volcanoes broke out, and heaped ashes and lava upon the surface; the sea worked against the land, and washed the coast steadily away; while in other places tawny rivers wandered through the plains and thrust their burden of mud in long banks far to seaward.

Thus the earth changed its surface, growing at one place, decaying away at another; and men began to realise that it had a history, beside which their own lives were short indeed. And yet it is only in the last hundred years or so that we have been able to read this history at all clearly, and even now we understand only that end of it which lies nearest to ourselves.

Before we go out and try to read a page or two of this history, we must learn something of the materials with which we have to deal. Of what, then, is the earth actually made?

As a matter of fact, we know only a very small part of the vast globe on which we live. The centre of the earth lies 4000 miles beneath us, and our mines and borings penetrate the great mass to a depth of only about a mile. But, as we shall see later, the outer layers of the earth have become wrinkled and folded, so that rocks which once lay far below the surface have been brought up within our reach. Hence in some places, immediately under the loose soil, we may find materials which were formerly ten or fifteen miles lower down; and this enables us to say that we have some idea of the constitution of the globe to a depth of fifteen miles from the surface. It is not much, this mere outer shell, fifteen miles thick all round the earth; but it is all we shall have to deal with, and we speak of this accessible region as the **crust of the earth.**

This solid crust is made of **rocks**. Any workman in a quarry will tell us, for instance, that granite is a rock, or that sandstone is a rock. But, when we examine these two materials, we see that they are made up of distinct particles which themselves are worth enquiring into. The granite has clear little lumps, like glass, in it; and dull white or pink bodies, which seem to break across in a regular manner, with smooth or step-like surfaces; and soft flaky things which reflect the light brilliantly, and which can be pulled away, or dug out with a knife, in the form of little shining plates. The sandstone, on the other hand, is made of practically one kind of material throughout, in the form of a number of hard and somewhat rounded grains.

In each case we call these constituents, having characters of their own, the **minerals** which compose the rock. The granite consists of at least three distinct minerals, the sand-

stone of only one. Now, if we break up a rock, and select a number of fragments of any one kind of mineral, a chemist will show us that this mineral is itself made up of certain chemical substances, which he can separate and accurately determine. He will be able to find out in what proportions these chemical substances are present, and will thus give us an account of the *chemical constitution* of the mineral.

But what about these various substances? They may be stated by our friendly chemist to be *chemical compounds*, and these can be further split up into their *elements*. Or, to take the simplest case, our mineral may possibly consist of merely one element.

Here we may remind ourselves of some of our chemical notions. We must go back, indeed, to the foundations of several sciences for the correct understanding of our rocks, and this first chapter is going to be a serious one, before we can fairly get out into the country and the open air. But we must remember that all the things with which we shall deal are quite natural, all come from the earth itself that stretches round us; and those parts of chemistry and physics which are possibly a little dull to us seem so merely because we cannot handle or directly observe the things about which we are being told. If we could see the tiny "atoms" moving in the "molecule" of a substance, we should probably be as delighted and as fascinated as if we were sitting on a mountain-peak and watching the great balance of the stars.

A **chemical element** is a substance that cannot be split up, by any means at present in our power, into any other substances with different properties from those by which it is itself characterised. It is thus the simplest kind of material known to us. Gold, silver, copper, and iron are elements; sulphur is an element; so also is carbon, well known to us in its commonest form, the "black-lead" of our pencils. There are now about seventy elements known, and others, at present doubtful, are likely to be added to the list.

The ancients regarded the earth as an element in itself, something existing as a foundation for other things, the remaining elements being air, fire, and water. What we now know as elements were often treated in earlier times as varied forms of the same fundamental material; but all

experiment has shown us up to the present that there are really, in this earth and throughout the mighty universe, a number of different kinds of matter. To be quite simple in our conceptions, we might wish to say that all elements are made up of different arrangements of particles of one first-formed matter; but that would be merely guess-work, and at present we cannot get beyond our seventy elements.

If we conceive the smallest particle of an element that can independently exist, we may call such a particle an *atom*. It will have a certain weight, and the atoms of different elements differ in their weights. But any quantity of matter that we can see, even with a microscope, must consist of enormous numbers of atoms.

The atoms are said to be grouped together in **molecules**, or "little masses." Chemists regard the molecule of certain elements as consisting of only one atom; in others, two or even six atoms may form the molecule. A molecule has been defined by Professor Tilden as "the smallest quantity which is able to take part in or result from a chemical change."[1]

A **chemical compound** is built up of molecules, each of which consists of atoms of more than one kind. In the simplest compounds the molecule consists of only two atoms, one atom of one element being combined with one of another. The elements have been shown to combine together in fixed proportions, forming compounds with distinctive properties. We may hence say that the molecule of a compound is the smallest particle into which the substance could be divided while yet retaining its peculiar chemical constitution. Further splitting might give us certain simpler compounds; but ultimately the actual atoms, or groups of similar atoms, of each molecule would be set free; in other words, the compound would separate into its elements.

All this may seem beyond human observation; but large quantities of molecules of a compound can be dealt with in our experiments, and large quantities of elementary molecules can be extracted by chemical processes from them. Or, on the other hand, we can cause large quantities of elementary molecules of different kinds to combine together to form large quantities of molecules of a chemical compound; and

[1] "Introduction to the Study of Chemical Philosophy," 1876, p. 4.

in either case, by weighing the quantity of each substance dealt with, we can find out in what proportions the elements are combined in any particular compound.

We may now glance backwards, and define an atom as the smallest quantity of an element that can be driven out of or caused to enter into a molecule of a compound in the subtle process of destroying or producing any of the known chemical combinations of that element. Here we have got down as far as we can go in the chemical constitution of a mineral. Minerals are made of chemical substances, which are made of molecules; these molecules consist of atoms either (*a*) of different kinds, in which case we are dealing with a compound, or (*b*) of only one kind, in which case our substance is an element.

Now we may try to arrive at a definition of a mineral. Let us look at those which we have separated from the granite—three materials evidently requiring distinct names, evidently differing markedly in their physical characters.

The clear little lumps are called *Quartz*, and do not tell us very much by their external appearance. They break across with irregular curving fractures, much as glass does; and they have in this case no regular shape. But they are transparent, and also very hard; for we cannot scratch them with a knife, and they, on the other hand, will scratch glass. Moreover, they will not soften and melt, as glass does, when held with a pair of forceps in the flame of a Bunsen burner —the gas-burner used in chemical laboratories or in ordinary gas-stoves. Clearly, they are not grains of glass.

If we give them to a chemist, he will find in them the two elements, Silicon and Oxygen, always in the proportion of one atom of silicon to two atoms of oxygen. Quartz is made, in fact, of the oxide of silicon, commonly called Silica. We may take any of these grains from granite rocks found anywhere in the world, and yet their chemical composition will be the same.

The dull white or pink bodies are called *Orthoclase*, or *Orthoclase Felspar;* these, as we have already noticed, have the property of breaking across regularly in certain directions—in two directions, at any rate—when struck with a hammer. This shows that their internal structure, the way in which the molecules are grouped together, differs from that of quartz. Moreover, we can see something of their

external shape; it is often regular, and, even on roughly broken surfaces of the rock, the larger orthoclases are seen to approach the form of small flat bricks. Then, in turning about the rock-specimen in the hand, some of these orthoclases seem to be built up of two parts; that is, one half of the orthoclase catches the light and gives a bright reflection, while the other half looks dull; clearly the planes of fracture are differently sloped in the two parts of the mineral, and it has not a perfectly simple internal structure.

A good knife will just scratch the orthoclase, if drawn firmly across it; but orthoclase will scratch ordinary glass; we thus learn that it is harder than glass, but not so hard as quartz. A little splinter of orthoclase can just be melted after holding it for some time in the flame of a Bunsen gas-burner.

Our chemist tells us that this mineral is more complex than quartz. He finds in it Silicon, Oxygen, Aluminium, Potassium, and generally Sodium. The proportion of these elements to one another is always the same, except in the case of the two last named. Sometimes there is only potassium present, and no sodium; sometimes sodium occurs, and then there is less potassium. We say that the potassium may be *replaced* in part by sodium without the principal characteristics of the mineral being altered. In such cases it must be a matter of general consent and judgment as to whether we are to call the mineral by a new name when such a replacement occurs. The atoms of sodium are lighter than those of potassium; but any difference in the weight of a given bulk of orthoclase, according as it contains potassium, or both potassium and sodium, would be very trifling. Cases often occur, moreover, where a lighter element replaces a heavier one, and yet the resulting variety of the mineral is actually heavier than the ordinary form. The molecules containing the lighter element must in such cases lie closer together, *i.e.*, there must be more of them in a given space, than occurs when only molecules containing the heavier element are present.

So we may note that the chemical composition of some minerals may vary slightly, varieties being set up which are grouped together under the common mineral name. A molecule of our typical orthoclase contains 2 atoms of potassium, 2 of aluminium, 6 of silicon, and 16 of oxygen. But in most

specimens of orthoclase there are some molecules in which two atoms of sodium take the place of the two atoms of potassium. When such molecules are shown by a chemical analysis to be numerous, we call the mineral variety Soda-Orthoclase.

Our third mineral in the granite is called *Mica*—the plate-like substance which is easily dug out with the knife, and which gives such a shining appearance to many specimens of the rock. Some micas are pale and silvery; others are quite dark, being bronze-coloured or black; but they have many characters in common. Again and again their proper form can be seen; their molecules are clearly capable of building up six-sided plates. This structure is so common that it cannot be accidental; and careful measures show that the angles of the hexagonal figure are kept the same in the same chemical variety. Such a structure is called a **crystal**; and a little observation will show us that the orthoclase also is in the form of crystals, though they have probably not been able to grow to such perfection. The mica splits very easily in one direction, so that we can flake off thin flexible plates; and even the blacker micas are no longer opaque when one of their thin plates is held up to the light. The mineral is quite soft, and can often be scratched by the thumb-nail.

The chemical composition of the micas is still more complex than that of the orthoclase felspar, but all common varieties contain Silicon, Oxygen, Aluminium, Potassium, Magnesium, Iron, and Hydrogen. The pale varieties contain little iron and usually little magnesium; the dark varieties are richer in these elements and poorer in silicon and aluminium. There may be a good deal of replacement of one element by another in the mica series, the general external characters being retained; and several different kinds or species of mica are recognised, and are known by distinct mineral names.

If we are so fortunate as to find a granite with a number of small hollows in it, perhaps half-an-inch or an inch across, such as occur in the famous rocks of the northern part of the Mourne Mountains, then we may see that all the minerals which we have discussed are capable of forming crystals, wherever freedom is given to them and when they are not too much squeezed together. In such hollows we find the mica, and the orthoclase, and the quartz itself, delicately crystallised, beautifully and regularly shaped, so

that persons looking at the handsome crystals in public collections often think that they have been artificially cut and polished. But you have only to go into the hills, and search in cracks and hollows for yourselves, to find that crystals occur naturally, and that they are, indeed, the form frequently adopted by natural chemical substances. And, further, the crystals of one compound usually differ from those of another; the sides make different angles one with another, even if the forms are very much alike; so that, by careful observation and measurement of the angles in various crystals, we can use the outer shape to help us in determining the nature of the mineral.

And now we can at last arrive at our definition. *A mineral is a natural substance, formed without the action of plants or animals. Its chemical composition is constant, or varies only by a well-defined series of chemical replacements. Under favourable conditions, it assumes a crystalline form.*

One mineral is known from another by a number of characters which must be considered all together; and these will be found stated in any text-book of mineralogy.[1] Let us run over the most important of these characters here.

1. **Colour.**—When there are several minerals in a rock, this character often clearly marks out one from another. But it is of far less importance than might be supposed, since many common minerals are coloured by some trifling impurity; a sort of stain runs through them, as it were, and in their pure condition they are colourless. Metallic ores, however, usually have characteristic colours; thus Iron Pyrites, the common iron sulphide, is brass-yellow, and Native Copper, the natural element, is copper-red. But, on the other hand, the red gem Ruby and the blue Sapphire are mere varieties of the same mineral species, Corundum, the composition of both being aluminium oxide coloured by a substance very insignificant in amount.[2] Hence we must

[1] Such as Hatch, "Mineralogy" (Whittaker & Co.); Rutley, "Mineralogy" (T. Murby).

[2] Artificial corundum has been coloured red (ruby) by adding chromium fluoride to the materials employed; and, curiously enough, the addition of this same substance in varying proportions has given rise to sapphires and to a green variety. Rubies have also been made by adding potassium bichromate, and sapphires by adding cobalt oxide (Fouqué and Lévy, *Synthèse des Minéraux et des Roches*, pp. 220 and 222).

rely on other characters besides colour in the determining of a mineral species.

2. **Transparency** or **Opacity**. — Some minerals are characteristically transparent—in thin flakes, at any rate. Here, again, impurities, and chemical changes as the mineral alters or decays, may render a clear substance finally opaque. Calcite (calcium carbonate) is typically transparent; Iron Pyrites is opaque, even when ground down thinner than a sheet of notepaper.

3. **Lustre**.—Some minerals reflect light brilliantly, like Quartz and Rock-Salt, which are said to have a "glassy lustre," because of their resemblance in this respect to glass. Others, as Iron Pyrites, look like polished metal, and are said to have a "metallic lustre." Others are quite dull and earthy, like Wad, one of the hydrous manganese oxides.

4. **Malleability** and **Brittleness**.—Some minerals can be hammered out without breaking, and are said to be "malleable," as Native Gold. Others are brittle, and fly to pieces when struck, as Iron Pyrites or Quartz.

5. **Hardness**.—This is one of the most important and useful characters. A mineral may be brittle, and yet may be soft enough to be cut into with a knife, like Copper Pyrites (sulphide of copper and iron); or it may be brittle, and yet too hard to be scratched with a knife, like Iron Pyrites. For our present purposes, we may note three kinds of hardness among minerals:—

a. Some minerals cannot be scratched by a good knife.
b. Some minerals can be scratched by a knife, but not by the thumb-nail.
c. Some minerals can be scratched by the thumb-nail.

Sometimes, in examining our rocks, it is difficult to say if some small projecting grain is hard or soft; we cannot determine whether we can scratch it, for fear of demolishing it or removing it altogether. In such cases we may draw it across the side of the knife-blade or across our thumb-nail, and see if it scratches either of these, in which case it is harder than the substance scratched. If the mineral is in the form of loose grains, like those broken from a sandstone, they can be stuck on to a piece of wood by some firm cement, such as the old bicycle-tyre cement, with their sharp little points sticking out above the surface; and

then, held by this handle, we can draw them across the knife or across the thumb-nail. Another plan is to squeeze them between two plates of glass, such as the slips used for mounting microscopic objects; it is easy then to see whether the little grains are scratching the surface of the glass.

6. **Streak.**—The colour of the powder of a mineral, produced by cutting into it or by crushing it out under a clean hammer upon white paper, is called its "streak." Every time that we use an ordinary pencil we see the streak of Graphite (one form of carbon), the mineral known popularly as "black-lead."

7. **Flexibility.**—Some minerals can be bent, especially in thin flakes, and remain in the form thus given to them. They are then said to be "flexible."

8. **Elasticity.**—Other minerals are said to be "elastic," when, like Mica, they spring back into their former shape after being bent.

9. **Specific Gravity.** — The statement of the Specific Gravity of a substance expresses its relative weight as compared with pure water at a temperature—in most English experiments—of 60° F. If we say that a mineral has a specific gravity of 3, we mean that any given bulk of it is three times as heavy as an equal bulk of water at 60° F. A cubic inch of it would thus weigh as much as three cubic inches of water at that temperature. Most minerals of common occurrence have a specific gravity between 2 and 3.5. Meerschaum, used for the bowls of pipes, is as low as 1.5, while Gold is as high as 19.3, and a native alloy of Platinum and Iridium actually reaches 23.

In the beautiful system of weights and measures invented in France, and now used by almost all civilised peoples, the specific gravity of a mineral or a rock at once tells us how much space a given weight of it will occupy, or, on the other hand, how much a given bulk of it will weigh. In this system the weight known as 1 gramme is the weight of a bulk of water occupying 1 cubic centimetre at a temperature of 4° C. Hence, adopting this temperature for the experiments, 1 gramme of a substance of a specific gravity of 5 will occupy 1-5th of a cubic centimetre, or 200 cubic millimetres, and 100 grammes of it will occupy 20 cubic centimetres. On the other hand, to take another example, 700 cubic centimetres of a mineral with a specific

gravity of 2.5 will weigh 700 × 2.5, or 1750 grammes. This is only one example of the admirable convenience of the "metric" system of weights and measures, when compared with the cumbrous and old-fashioned systems which English-speaking children have unfortunately still to learn.[1]

10. **External Form.**—In rocks so many causes tend to prevent a mineral from getting a fair chance of assuming a crystalline form, that the outer shape is of small importance compared with many other characters. But to the mineralogist it is a great means of distinguishing mineral species, and the forms observed are grouped in six "systems" according to their greater or less degree of symmetry. The smooth surfaces of unbroken crystals, making definite angles one with another, are called their *faces*, and the number of these faces, and their relations to one another, show the degree of symmetry of the crystal.

If you cut an exact square out of paper, you will find that it is a highly symmetrical form; *i.e.*, you can cut it across in four directions so that the two pieces produced are equal and of the same shape, covering one another exactly when the one piece is turned over so as to lie upon the other. Then, if you cut out two equal squares, and stand them upright in such a position that a line joining their centres is at right angles to both of them, you have a still more symmetrical arrangement formed by two "faces" of a possible crystal; a pin may be run through the centres of the squares so as to hold them in this position. Now make the distance between the squares equal to the length of one of their sides, and close in the figure by four other squares of the same size; we now have a cube, bounded by six similar faces. This is a solid figure—it represents a common natural crystal-form — which is of the highest known degree of crystal symmetry. You can carve nine such forms out of some soft stuff, say a potato, and place them side by side; each one may now be cut through in a different direction, so that in each case two halves result precisely similar to one another, being merely reversed in position with regard to the centre of the cube. The surface of division between the two halves is in each case called a *plane of*

[1] For an account of simple apparatus for determining specific gravity, and for measuring the angles of crystals, &c., see "Aids in Practical Geology" (Griffin & Co.), 4th ed., pp. 15–32.

symmetry; the half on one side of it is, as it were, an exact reflection of that upon the other. Hence we say that the cube has nine planes of symmetry. A plane of symmetry must always pass through the centre of the crystal.

The six systems under which crystals are arranged have received names which need not be explained here, but which may be stated for ready reference. They are:—

I. The *Cubic* system, with 9 planes of symmetry.
II. The *Hexagonal* system, with 7 planes of symmetry.
III. The *Tetragonal*, with 5 planes of symmetry.
IV. The *Rhombic*, with 3 planes of symmetry.
V. The *Monoclinic*, with 1 plane of symmetry.
VI. The *Triclinic*, with no plane of symmetry.

A Triclinic crystal, then, cannot be cut in any direction so as to produce two symmetrical evenly balanced halves.

The symmetry of natural crystals is often spoilt by certain faces growing larger than the corresponding ones on the other side of what ought to be a plane of symmetry; but mineralogists discover what the symmetry properly should have been by measuring the angles between the faces and noting how they repeat themselves exactly in certain sets all round the crystal.

The description of crystals is outside the range of this little book; when we have become interested in observing their various forms in nature, we shall some day want to turn to one of the simple works on mineralogy for further guidance. At present I have tried to give some slight idea as to why we say a mineral crystallises in such-and-such a system.

The same chemical substance sometimes crystallises in two, or rarely in three, systems. In such cases we have two or even three mineral species, the chemical composition of which is identical, but which differ in hardness and specific gravity, and perhaps in other physical characters, as well as in outward form.

11. **Twinning.**—Some crystals are built up of two or more parts placed in a singular relation one to another. If you take two bricks out of a child's toy-box, and paint one of the flat sides of each red, and stand the two bricks up on end parallel to one another, their red sides facing in the same direction, they may be regarded as two crystals standing in similar positions. If we stick the two together, with the red side of one touching the plain side of the other, we have

merely, as it were, made a crystal of twice the bulk of each of the original separate ones. But if we turn one brick round, either on the end on which it is standing, or else by lifting it, turning its lower end upwards, and setting it down again, then the two red sides either face one another or face away from one another. Stick the two red faces or the two plain faces together, and we produce a form in which the two halves are reversed in position, and one must be turned back again through 180° before it corresponds in position with the other. The parts of some crystals are related in this curious way to one another, and such compound forms are called "twin-crystals." It is as if the original crystal had been cut through the centre, and one half had been turned through an angle of 180° and then stuck against the other half again. This may take place several times in one crystal, the molecules in one layer building up a structure which differs in position by 180° from that in the adjoining layer. Orthoclase felspar, which we have already seen in the granite (p. 7), is thus simply "twinned," and the two halves catch the light differently, because the internal structures are not parallel in them; other species of felspar are repeatedly twinned, with perhaps twenty layers in a thickness of a millimetre.

12. **Cleavage.**—In examining the felspar and mica of a granite rock, we saw how these minerals broke regularly, how they split by preference along certain regular planes. Such minerals are said to be "cleaved," or to have a "cleavage." Planes of weakness run through them, which are found to be related to the crystalline form when this also is developed. These "cleavage-planes" are, in fact, always parallel to some plane that might occur on some possible crystal of the mineral. Again and again we know by the occurrence of cleavage that we are dealing with a crystalline mineral, that is, one in which the molecules are duly arranged, even though the outer form was never perfected or has been worn down and rubbed away.

Some minerals, like Calcite, have three perfect sets of cleavage-planes, and can hardly be broken except along these planes, every tiny fragment coming away like a little independent six-sided crystal. Other minerals, like Quartz, are known by the absence of cleavage, and consequently by breaking in any direction with an irregular curving fracture.

13. **Magnetism.**—A few minerals can be attracted by a magnet when finely enough broken into powder. Magnetite (one of the iron oxides) and Pyrrhotine (an iron sulphide) attract particles of their own powder.

14. **Chemical Composition.**—This all-important character is here placed last, owing to the special and often laborious tests required for its correct observation. Many minerals cannot be distinguished by a mere qualitative examination, but we must ascertain the exact proportions in which their constituents are present before we can assign them to their proper species. However, with good reference-books to hand, a few simple tests for particular chemical elements, combined with the observation of the physical characters of the mineral, will commonly give us the clue without a complete quantitative analysis. Unfortunately, the silicates are among the most abundant substances in the earth's crust, and the minerals formed from them are by far the most difficult to analyse. The elements combined with the silicon yield their characteristic reactions much more feebly than when combined only with oxygen, with chlorine, or with sulphur; most mineral silicates, in fact, resist simple attempts to split them up, and yet the proportions of their constituents are a fundamental matter in the determination of their exact species.

Now that we know the prominent characters of a mineral, we may proceed to define a rock. *A Rock is a natural aggregate of mineral particles, either of one or of different kinds.* The particles may be in the form of crystals, closely fitted into one another; or one of the minerals may serve as a cement to unite the whole together; or the mineral particles may lie loosely together, as in sand. Sometimes, but rarely, the materials have not separated out into distinct minerals, but have remained as a natural glass, all melted together and uncrystallised.

If we search through the rocks known to us from all quarters of the globe, we shall soon find that the earth's crust is formed mainly of a few minerals repeated over and over again. Specimens showing most of the essential characters of these minerals can be obtained from any geological dealer; and they will serve as a reference-series with which to compare the specimens that we may collect

for ourselves in the open air. We will now run over the list of the minerals that are most important for our present observations.

I. *Oxides.*

Quartz.—Silicon oxide (silica). Colourless. Transparent to milky; glassy lustre. Harder than the knife. Specific gravity 2.65. Hexagonal system of crystallisation; commonly known in small grains, or as duller and more milky masses filling cracks in rocks; crystallises in hollows, &c., as six-sided prisms capped by pyramids, which also have six sides. No cleavage. One of the very commonest minerals. *Sandstone* is formed of grains of quartz.

Opal.—Uncrystallised silica, partly hydrous. Glassy and transparent. The variety used as a gem contains layers of different density, which produce a play of colours. Unscratched by knife. Specific gravity 2.25.

Chalcedony (Flint).—Minutely crystalline silica, with probably a little opal. Unscratched by knife. Formed in cracks and hollows of rocks, or as lumps replacing limestone (common flints).

Magnetite.—Iron oxide, each molecule containing 3 atoms of iron to 4 of oxygen. Black and opaque. Lustre somewhat like that of the black-lead in a pencil. Harder than knife. Specific gravity 5. Cubic system, crystallising in little double pyramids, the faces of which are eight equilateral triangles. Easily attracted by magnet, and attracts iron filings, as well as its own powder. Occurs often as tiny grains scattered through a rock.

Limonite.—Hydrated iron oxide, the molecule containing 6 atoms of hydrogen, 4 of iron, and 9 of oxygen. Warm yellow-brown; opaque and usually dull. Sometimes quite soft and powdery. Streak yellow-brown. Crystalline form unknown. This mineral consists of common iron rust, and forms most of the brown stains in rocks, resulting as it does from the decomposition and alteration of minerals containing iron. Magnetite is often coloured brown by this action on its exterior.

Water.—Hydrogen oxide. The solid form of water, **Ice**, occurs in vast masses on the earth's surface, and must thus be considered as a common rock-forming mineral. Hexagonal system.

II. *Chlorides.*

Rock-Salt.—Sodium chloride. Colourless, unless tinged with an impurity, such as limonite; transparent; lustre glassy on good surfaces. Easily scratched by the knife, and even by the thumb-nail. Cubic system, forming cubes. Soluble in water, and easily known by its taste.

III. *Sulphides.*

Iron Pyrites.—Iron sulphide, with 2 atoms of sulphur to 1 of iron. Brass-yellow and opaque; metallic lustre. Not scratched by knife. Specific gravity nearly 5. There are two species included under this name: one, called **Pyrite,** crystallises in the cubic system, often forming neat little cubes, and being well seen in slaty rocks; the other, **Marcasite,** is rhombic, and commonly occurs as a replacement, or forming casts, of fossils, so that we see shells, and even fishes' teeth and spines, preserved in this bright brassy material. Marcasite, however, decomposes rapidly, giving off fluffy white products; while Pyrite can be easily kept in collections. Pyrite alters slowly in nature, where exposed, into soft brown powdery limonite.

IV. *Carbonates.*

Calcite.—Calcium carbonate (1 atom of calcium, 1 of carbon, and 3 of oxygen in each molecule). Colourless and transparent. Lustre almost glassy. Easily scratched by knife, and thus at once distinguished from quartz. Specific gravity 2.72. Hexagonal system, forms very various; but all break up along three perfect series of cleavage-planes when struck. Calcite is a very common mineral, forming the rocks called *Limestone* and *Marble,* in which it is often coloured by impurities. When a drop of acid, such as hydrochloric or sulphuric acid, or strong vinegar, is placed on calcite, the mineral begins to dissolve, freely giving off bubbles of carbon dioxide gas.

Aragonite.—Same composition as calcite, but rhombic in crystallisation. General characters similar, but specific gravity 2.93. Rarer than calcite; but many sea-shells are

made of aragonite, while others are made of calcite. Behaves like calcite with acids.

Dolomite.—Calcium carbonate and magnesium carbonate in equal proportions, forming a compound carbonate. The constituent elements are thus calcium, magnesium, carbon, and oxygen. Generally resembles calcite, even in cleavage, but specific gravity 2.85. Hexgonal system. Gives off little or no gas in acid unless the liquid is heated.

Chalybite.—Iron carbonate. Faintly brown; lustre almost glassy. Generally resembles calcite, even in cleavage, but specific gravity nearly 4. Hexagonal system. Often occurs imperfectly crystallised, forming great nodules and lumps in clays, and often surrounding fossils.

V. *Sulphates.*

Gypsum.—Hydrous calcium sulphate, each molecule containing 4 atoms of hydrogen, 1 of calcium, 1 of sulphur, and 6 of oxygen. Colourless and transparent; glassy lustre. Scratched by thumb-nail, and thus at once distinguished from calcite. Flexible in thin plates. Specific gravity only 2.3. Monoclinic system, often forming somewhat flat crystals; often, however, fibrous. One cleavage very conspicuous. Occurs in clays, as detached crystals and as plates and veins; when present in considerable quantity, forms the rock known as *Alabaster.*

VI. *Silicates.*

First we may take three of the group known as the Felspars.

Orthoclase Felspar.—Potassium aluminium silicate, usually with some sodium, as we have already mentioned farther back (p. 7), when we were considering the chemical composition of minerals in general. Colourless, with glassy lustre, when quite unaltered, but commonly duller white or pink. Just scratched by a good knife. Specific gravity 2.56. Monoclinic system, usually in forms somewhat flattened in one direction. Crystals almost always simply twinned, as can be seen upon broken surfaces. Two perfect cleavages, at right angles to one another, whence the name Orthoclase.

Albite Felspar.—Composition similar to orthoclase, but sodium entirely takes the place of the potassium. In

general appearance like orthoclase, but only rarely of a pink colour. Just scratched by knife. Specific gravity 2.6. Triclinic system; repeatedly twinned, so that the crystals are built up of delicate alternating layers. Two good cleavages, which are not exactly at right angles.

Anorthite Felspar.—Calcium aluminium silicate, the molecule containing 1 atom of calcium, 2 atoms of aluminium, 2 of silicon, and 8 of oxygen. Resembles the other felspars in appearance; commonly dull white. Just scratched by knife. Specific gravity 2.72. Triclinic system; repeatedly twinned.

The species of felspar form a closely connected series, **Oligoclase**, sodium calcium aluminium silicate, and **Labradorite**, calcium sodium aluminium silicate, being forms intermediate in composition between albite and anorthite, and also crystallising in the triclinic system; the former contains more sodium than calcium, and the latter more calcium than sodium. These very common minerals, the felspars, provide us, as we shall see, with important products when they decay away. All the felspars except orthoclase, being triclinic, have their two chief cleavages not perpendicular to one another, and are classed together as "slanting-cleaved" or **Plagioclase** felspars.

Next comes a group of minerals rich in magnesium and iron.

There is one series known as the *Amphiboles*, from which we may select the common species **Hornblende**. This is a complex silicate of magnesium, iron, aluminium, and usually some calcium. Colour dark green, dark brown, or black; glassy lustre when fresh. Scratched by knife, but not easily. Specific gravity 3. Monoclinic system; often occurs as long prisms and fibrous groups. Two fair cleavages at about 120° (precisely 124° 30′) to one another.

From another important series, the *Pyroxenes*, some of which are monoclinic and some rhombic, we may choose **Augite**. In composition this mineral may be identical with hornblende; it is similarly dark in colour, is just scratched by the knife, has a specific gravity of 3, and is monoclinic. But it typically forms shorter prisms, and the angles between the faces of the crystals differ from those of hornblende. The two cleavages similarly differ, being practically at 90° (precisely 92° 55′) instead of at about 120°. Hornblende

and augite are interesting examples of how the same substance may assume, under different conditions of growth, a distinct set of crystal forms. If hornblende is melted up and made to crystallise again on cooling, the forms produced are those of augite. On the other hand, in rocks a slow natural change goes on, by which the molecules in crystals of augite rearrange themselves and produce crystals of hornblende. Hornblende thus seems to be the more lasting and settled and steady-going form to which these molecules give rise. Some pyroxenes, closely allied to augite, contain soda molecules, and may be styled **soda-pyroxenes**. The **rhombic pyroxenes** do not contain alumina, being silicates of magnesium and iron, with about 50 per cent. of silica.

Olivine.—Magnesium iron silicate, without aluminium, and with less silica than the pyroxenes and amphiboles. Yellow-green or brownish yellow; transparent, with glassy lustre, when fresh, but decomposes readily to dull brown and deep black-green patches. Not scratched by knife when fresh, but commonly quite soft and altered. Specific gravity 3.3 when fresh. Rhombic system, but usually occurs merely as somewhat rounded grains. Two cleavages often seen, breaking the crystal up into minute brick-like masses. During alteration, the mineral takes up water, turns out some of its iron atoms, and forms the soft green, black, or reddened mineral called **Serpentine**. Rocks largely composed of olivine thus decompose, and form the ornamental serpentine rocks.

We have already (p. 8) discussed some of the characters of the next minerals, the *Mica series*. **Muscovite Mica** is a hydrated silicate of potassium, sodium, and aluminium, differing from orthoclase by containing some combined water, and by the silica forming only about 45 instead of 65 per cent. of the total weight of the mineral. Colourless to bronze-brown; transparent in flakes, and used for covering gas-globes and lamp chimneys. Silvery lustre. Just scratched by thumb-nail; the knife scratches it very easily, with a characteristic grating sound. Specific gravity nearly 3. Monoclinic; commonly forms six-sided plates. Perfect cleavage, splitting up the crystals into the most delicate transparent layers. These layers are elastic.

Biotite Mica is a hydrated silicate of potassium, aluminium,

magnesium, and iron, the proportion by weight of the silica being less than in muscovite. Dark bronze, black, or dark green; translucent in thin flakes. Hardness and other external characters like muscovite. It is sometimes impossible to distinguish specimens of muscovite and biotite without chemical or microscopic tests. For our purposes in our walks abroad, it will be sufficient if we can recognise such a mineral as one of the Mica series.

Chlorite.—Hydrous aluminium magnesium iron silicate. Dark green, generally resembling a green mica, but somewhat duller, and very easily scratched by the thumb-nail. This mineral commonly occurs as a product of the slow alteration of amphiboles, pyroxenes, and micas, and gives a prevalent green tinge to many decomposing rocks.

Kaolin.—Hydrated aluminium silicate, the molecule containing 4 atoms of hydrogen, 2 of aluminium, 2 of silicon, and 9 of oxygen. White and powdery, dull in lustre, resembling flour. Specific gravity about 2.5. Rarely found crystallised, when it forms small six-sided plates. Kaolin is the common product of the decomposition of potassium and sodium felspars and of similar minerals rich in aluminium; mixed with iron oxides and animal and vegetable stainings, it forms the bulk of all the common rocks called *Clays*.

We have now enumerated some twenty-six minerals which we shall commonly meet with in our observations of the earth's crust. One point must have been forced upon us in glancing over the descriptions. These common minerals consist of only a very small number of the seventy known chemical elements. The part played in the earth by the rarer elements is possibly of great importance. Small additions of them to a mineral may, perhaps, change its mode of growth or its whole physical characters and external aspect; just as, in making metallic castings, very small admixtures of some element may make a world of difference in the toughness and hardness of the finished product. But, if we have now correctly enumerated the commonest minerals of the earth's crust, the bulk of that crust, at any rate, must clearly be made up of a limited number of constituents.

Mr. F. W. Clarke[1] gives us the following estimate of

[1] *Bull. U.S. Geol. Survey*, No. 78 (1891), p. 39; No. 148 (1897); and especially No. 168 (1900), p. 15.

the proportion *by weight* in which the elements occur in the "entire solid crust of the earth":—

Oxygen	47.29	Carbon	.22
Silicon	27.21	Hydrogen	.21
Aluminium	7.81	Phosphorus	.10
Iron	5.46	Manganese	.08
Calcium	3.77	Sulphur	.03
Magnesium	2.68	Barium	.03
Sodium	2.36	Chromium	.01
Potassium	2.40	Chlorine	.01
Titanium	.33		
			100.00

We may conceive that the oxygen, which forms half the weight of the earth's crust, is distributed among the other elements, and we may state the components of the crust as oxides, which is the form in which they commonly occur when they build up minerals. Thus aluminium silicate may be regarded as a combination of silica (silicon oxide) and alumina (aluminium oxide). Water, again, is an oxide of hydrogen, and calcium carbonate is a combination of carbon dioxide and lime (calcium oxide). When stated thus, we find that Silica forms about 59.7 per cent. of the crust by weight, Alumina 15.4, Lime and Magnesia (magnesium oxide) about 4.5 each, Soda (sodium oxide) 3.6, and Potash (potassium oxide) 2.8 per cent. A large amount of the available oxygen is thus bound up with silicon, the silica crystallising as quartz, or forming silicates by union with the other oxides. Of these common oxides, only a few form minerals without further combination: these are, firstly, silica; secondly, the iron oxide in which 2 atoms of iron are united with 3 of oxygen (which forms a deep-red ore called *hæmatite*); and, thirdly, water (which crystallises in the hexagonal system as *ice*). The mineral magnetite is really produced by the union of two distinct oxides of iron, one constituted as above stated, and the other consisting of molecules with 1 atom of iron to 1 of oxygen.

When we have thus set our ideas in order, and have got our small collection of typical rock-forming minerals together, we shall often have hard work in determining the constituents of the rocks that we bring in from our country expeditions. In a coarse-grained granite we can pick out the minerals from one another, and see clearly that they are of distinct kinds. But in many rocks the mineral particles are exceedingly minute, and the whole mass looks at first as if

it were composed of only one kind of material. We may overcome this difficulty by various methods which have been devised for **separating the constituents of rocks.**

The rock must first be broken up with a hammer, all the fine dust and smaller fragments being preserved, together with the larger pieces. A great deal can then be done by simply throwing the whole material into a shallow pie-dish or a soup-plate, and washing well with water. The water is poured upon the powdered rock, is well shaken, and is then poured off again into another dish. It carries with it much of the finer material, and this can be entirely removed if the operation is again and again repeated. Soon we have remaining in our original dish only the coarser and less useful fragments, and we can give our attention to the second dish.

Here it may be worth while to make a further separation, and to wash off the very finest material into a third dish. Our object will be to produce a material in which the particles are so small that each consists practically of only one kind of mineral. We must examine the product from time to time with a hand-lens, until we can see the lighter and darker constituents lying cleanly side by side. Then we can take a small quantity of this material—say, enough to cover a sixpence—and dry it gently on a clean piece of brass or iron over a lamp or candle. The iron may be held with a pair of pliers during the gentle heating.

When dry the particles will roll about freely, and any specially desirable ones can be picked out from the rest. A moist colour-brush is good for this purpose, the lens being held in one hand and the brush in the other. The brush is dipped in water and a fine point is given to it; any of the little grains stick to it when touched, and can be deposited in some safe vessel for examination. The common circular earthenware palettes of children's colour-boxes are good receptacles for the minerals during sorting.

When we have thus extracted a number of examples of the minerals that look different from one another, rejecting all grains that are composed of more than one mineral, we can test these materials in various ways. Their hardness can be found by sticking them on to a handle of wood as suggested on p. 10, and drawing a knife, or other minerals of known hardness, or the thumb-nail, across them. Refined but easily applied methods have been invented for determin-

ing even the specific gravity of minute grains.[1] Chemical tests can also be brought to bear. A drop of hydrochloric acid, or other chemical reagent, can be placed upon an isolated mineral grain, which is suitably supported on a square of glass, and the resulting action or absence of action can be examined with a lens or a microscope.

The microscope was used by the French observer, Cordier, in 1815[2] for the determination of tiny mineral specimens such as these; and he compared his particles with those obtained by powdering up known minerals. In this way he proved that some rocks, which were supposed to be of uniform constitution throughout, were in reality composed of several distinct minerals, held together, in some cases, by uncrystallised glassy material lying between their grains.

Cordier used sieves of various degrees of fineness, through which to sift the powdered materials. This forms one of the very best means of separation; but the production of a suitably fine sample by mere washing is quite practicable, and is so simple that any one can attempt it with ordinary household-apparatus. But the work must be done near a sink, or in some place where no one will object to the splashing of a little water.

Magnetite, and fragments in which even a small proportion of magnetite occurs, can be picked out from powdered rocks by merely passing a dry magnet over the powder. The magnet must be in no way damp, or grains of the other minerals will stick to it if touched.

When it is necessary to know how the minerals in a rock are related to one another, and what their exact arrangement is in the mass, a flat surface can be produced on part of the rock-specimen by grinding; it can then be polished, and can be inspected with the lens or microscope. Thus the various mineral constituents may usually be clearly seen in place. The grinding-down can be done most conveniently by getting a piece of lead about six or seven inches square and strewing emery upon it. Emery of suitable fineness is called "90-hole," since it is sifted through a sieve with 90 holes to an inch, or 8100 to the square inch. Emery can be bought cheaply from an oil-and-colour merchant or an ironmonger. The emery powder is scattered on the lead

[1] See "Aids in Practical Geology," p. 28.

[2] *Journal de Physique*, tome lxxxiii. (1816), pp. 135, 285, and 352.

plate, and is made into a thin paste with water; then a small lump of the rock is held in the hand and is rubbed about on the plate with a circular motion, being all the time pressed firmly down. Water must be added from time to time. When a fairly smooth surface has been produced, the specimen should be washed and further ground down upon a square of plate-glass, cut from the "remainders" of a glazier's yard; on this glass a finer emery known as "flour-emery" should be scattered. Plenty of water must be used. The specimen is again washed, and the surface may often be examined successfully in a wet state under the microscope, appearing then as if polished. Or it may be varnished over, which serves the same purpose in producing a good smooth surface. Or it may be fairly polished by rubbing briskly on an old worn carpet, the dust in this helping the operation. The rock gets rather hot to hold, by reason of the rapid friction, and water cannot now be used; but the brisk work of a very few minutes will produce a useful polish. Professional polishing is done with rouge (powdered hæmatite) upon a stretched surface of wash-leather.

Sometimes it is a great advantage to grind a piece of the rock so thin that the light shines through it, in which state it can be examined as a transparent object under the microscope. This is by no means so difficult as at first appears, and any friend accustomed to use the microscope would be willing to assist in the final mounting of the specimen. The simplest way to prepare **rock-sections** is as follows:—

1. Choose a fragment of the rock, as flake-like and as thin as possible, and about an inch square, and grind down one surface with emery. (See directions above given.)

2. Finish this surface carefully by rubbing, with plenty of water, on a Water-of-Ayr hone, to be obtained of any good tool-shop.

3. Get some ordinary glass slips for mounting microscopic objects, measuring three inches by one inch; dry the rock-flake, and cement its smooth surface to one of these with stiff Canada balsam (procurable from a chemist). Heat the slip gently on a piece of metal supported over a lamp, until the balsam slowly gives up the spirit in it, and remains liquid only by reason of the high temperature. This stage can be judged of by dipping the end of a wooden match from time to time into the balsam round the specimen. The balsam

brought away cools quickly in the air, and when it is seen to become brittle on cooling the operation has gone far enough.

4. Then press the specimen firmly down upon the glass slip, to drive out any bubbles under it; remove it from the lamp and let it slowly cool.

5. Now, using the glass as a handle, grind down the remaining rough surface of the rock. In this way the specimen will gradually become possessed of two parallel surfaces; it will become thinner and thinner, until light begins to be visible through it; and it must be finished with flour-emery, and finally on the hone. With care, all parts of it can be made equally thin, and it may then be washed well and allowed to dry.

6. Cover the thin section thus made with Canada balsam, and place on this a thin cover-glass, such as microscopists ordinarily use. Dry the balsam slowly as before, being very careful to avoid overheating and the consequent production of bubbles.

7. The section will now be ready for the microscope. Any balsam that has oozed out upon or round the cover-glass can be lightly cleaned off with a cloth dipped in spirits of wine.

For casual examination, the finished section need not be covered, but may merely be moistened with water, and can thus be examined under the microscope.

A good rock to begin upon is a fairly hard chalk, a substance which grinds down easily and which is yet permeated by the balsam and rendered coherent. Sections of chalk can be prepared entirely on the Water-of-Ayr stone.

So much for indoor considerations and observations. In our walks abroad we must carry two instruments, a hammer and a pocket-lens. The **hammer** may weigh about a pound, and its head should have a good chisel-like edge on one side and a square steel face on the other. The chisel-edge is best placed perpendicularly to the direction of the handle of the hammer.

A small stone-mason's **chisel** is always worth carrying, and even a light hammer and a chisel combined will often do what a heavier hammer alone could not effect. Large blocks of stone can be wedged out by steadily driving the chisel into some natural crack.

The best **pocket-lens** for our purpose is the common "triplet," with three lenses of different power folding up into one cover.

And now we can at last set off on our travels. We have taken pains to learn something of the alphabet of our subject; and any one of us may hope in time to apply these studies to the actual examination of the earth. In our own immediate surroundings—even in the muddy rivers that run through great cities—there is something to be observed, something far more important and interesting than anything which we can learn by the mere reading of books indoors. If I describe in these pages the details of some landscape that is familiar to myself, or bring together for illustration the features of several landscapes, it is with the hope of encouraging each reader to make similar and better observations in his outdoor wanderings for himself. It is well to note down our impressions, making little sketches, however rough, of what we see—the form of a boulder, the series of rocks exposed in a quarry, the outline of a hillock or of a mountain-range. Until we put our notes on paper, trying to be as exact as possible, we really do not know how many things we may notice in a short day's ramble; and, when we have written them down, we constantly require to go back again to fill up some gap in our observations. And even then we feel a desire to fit things together, so as to explain them; whereupon we shall find that a single lifetime and our individual wits are quite insufficient for the purpose. We must take counsel of various other people; we must examine their books, and what they have extracted out of previous centuries of books; and all the time we must be on the look-out, for possibly it may be given to one of us to see what no one before has seen exactly in the same way. And then we shall have made a geological discovery.

After all, it matters very little whether the persons who have gone over the ground before us have or have not seen all that we can see. The delight of thus wandering, with our eyes wide open, across the airy moorland or along the shingle of the beach, is one that will grow upon us, and that can never again be taken away from us or lost. We shall be every hour finding out things for ourselves, no longer pent up in museums or laboratories, but among the broad ridges of the world, seeing how the wind, and the streamlet, and the ocean, and the rocks, all work together, with the great sun shining overhead.

CHAPTER II

A MOUNTAIN-HOLLOW

Now let us come out and see what is happening all round us. Every spring we notice how the trees bud forth again; how the tender coils of the ferns begin to push up through the dead brown leaves that have coloured the hillsides all the winter; how the primroses look out and shine like stars along the green borders of the lane. In the summer we watch the corn changing, and the fruit reddening on the boughs; in the autumn we notice that the woods are golden, and that the leaves soon begin to fly through the air, as if some caliph of the Arabian Nights were scattering coins in the sunlight. Then, from one year to another, we can see how animals grow up; the little kitten changes, and becomes a quiet old cat that loves to sit by the fireside; the white lambs, which used to run up to us inquisitively in the fields, soon alter into thick-bodied and uninteresting sheep. All these things grow, and go on changing; but the fields themselves, the broad slopes where the heather gathers, the barren rocks above, and the long dark ridges of the hills, all these seem to remain, and never to grow, or alter, or decay.

Well, let us set forth on our travels, and keep our eyes well open. Perhaps we may find out that the hills are changing after all.

We must imagine that we wake up on a fine clear morning at the foot of some of our wild mountain-masses in the British Isles—perhaps at the head of Windermere, or in the passes around Snowdon, or in Perthshire, along the great Highland border, or among the purple slopes of Kerry or the barren moors of Donegal. Our little farm-house lodging lies by the high-road up the glen; far away we can see the cart-track winding, now crossing some spur above the stream, now descending to the valley-floor; and on either side of it a few cottages stand dotted about the lower slopes. Above them the steeper moorland rises, grey-green and purple, and

crossed here and there by bands of stones, or cut into by rushing little streams.

We must climb to-day steadily up into the hollows of the mountains. We must leave the white cottages far below us; and, as we pass through the last gate in the stone wall, we find ourselves on the open moorland. A few grey blocks of stone lie half buried in the furze and heather; there used to be many more of them, before the farmers gathered them and laid them together to make the walls. Some were so large that they had to break them up with gunpowder; you can still see the marks of the boring-tools on them, where the holes were made in which the blasting-cartridges were placed.

A little above us, a few huge blocks remain untouched; and one or two are as large as a labourer's cottage. If we walk round one of these, we shall very likely find a number of smaller stones wedged up against it, as if they had come tumbling down the slope and had been stopped by their bigger brother. Every now and then we hear faint sounds of water trickling; it is making its way down among the stones that have become quite buried in the grass. If we dig for a little while with a walking-stick, we may be able to see the tiny streamlet flowing; or at any rate we can stoop down and hear it much more clearly. We see that the hillside is partly made of blocks of stone, loosely piled on one another; and the water can find a path between them. It washes along earth and sand as it flows downward, and sometimes in this way it fills up the spaces between the stones, and has then to move away into another course. If you put your hand down into the crevices, you will probably bring up some of the fine sand.

How far down does this assemblage of loose blocks extend into the hill? Well, let us come across to the big stream which here foams down the mountain-side. When we were down below, it looked like a white streak; but, now that we stand by it, we find that it is a fair-sized river. The banks are twenty feet or so in height, and they show us the stuffs of which the ground hereabouts is made. Great blocks of stone stick out on the steep sides, heaped together in a coarse sand. Down where the stream itself is running, we can see the solid rock; and here and there there are fine deep pools, or narrow gorges which look as if they had been

cut out by a mason. So we learn that there is solid rock under us, forming the mass of the mountain, covered by perhaps twenty feet of the loose gravel with the big stones scattered through it.

What we have seen in the side of the great stream is called **a section**; it is as if we had cut down into the earth for ourselves and had seen the different rocks lying there one upon another. A slice of wedding-cake shows, in the same way, the sugar, and the almond-layer, and the cake itself; "in section." Every quarry and every railway-cutting similarly give us a geological section.

Now we must move on upwards, although the slopes grow steeper; and there are now plenty of blocks among which we have to pick our way. Little cliffs of solid rock also stand out above us, and we must climb up by the gullies through them, or find a way round to right or left. The loose blocks, half buried in the grass, are made of the same materials as the cliffs; here and there we may find a puzzling stranger, but the vast majority seem just to have fallen from the crags above us. This observation will very soon be useful, as we reach the higher levels of the mountain.

If you kick a stone from under you, it goes bounding down across the grass, it leaps over one or two of the little cliffs, and so descends until it rests on some lower ledge of the hillside. Every time that the sheep walk along the paths made by them, a few stones become dislodged and move farther down into the valley. So that the surface of the slope is changing, as surely as the bracken changes and dies away in winter; only it might be many, many years before we should notice that the whole mountain was thus decaying.

If we follow up the stream itself, we shall see that something interesting is going on there. The deep pools often occur at the foot of waterfalls, and here the water is violently churned up, white and foaming, while it swirls away steadily to its outflow at the farther end of the pool. If it is a time of flood, we shall see little more than this commotion; but during a dry spring or summer we can walk out on the exposed rocks right into the middle of the stream. In these rocks there are a number of circular hollows, sometimes imperfect and open on the side that lies farthest up the stream; some are a foot or more across,

others are too small to get one's hand into; and in each there are one or more rounded pebbles, and often a good deal of fine sand.

At first it looks as if these materials had been washed down and had fallen naturally into the holes; and this is certainly true of most of the smaller stones and sand. But the holes themselves require explanation, for some of them resemble the drill-marks in the stones blasted by the farmers

FIG. 1.—POT-HOLE IN BED OF STREAM, GLENARIFF, COUNTY ANTRIM.
(*Photographed by Mr. R. Welch.*)

down below. Their inner surface is beautifully smooth, and their depth is often greater than their width; now and then there are a few grooves running round the inside, as if the drill for a time had tended to make them rather larger.

If we choose the simplest case, we find that there is one large pebble in the hole, and we can move it round and round when we reach down to it with our fingers. The fact is, that the pebble has drilled out the hole in which it lies.

At some time or other a stone got wedged in one of the cracks of the rocky bed of the stream; the rush of water kept turning it round and round, and supplied it with sand, which helped it to cut into the rock. Every one knows how a grain of hard sand, caught in between, let us say, a polishing-cloth and the handle of a bicycle, will cut deeply into the metal at every movement of the hand. Thus the stone bored its way down, until no force of the stream could dislodge it again; and, every time that the flood comes over it, it works away in its little prison, deepens the floor of it, and smooths and polishes the sides (fig. 1.).

Such holes are called **pot-holes**, and may be seen in hundreds when the stream is low. If they can be made so freely in these ordinary rapids, we can guess what is going on under the waterfalls themselves. Several pot-holes often cut into one another, and finally form one large one; and in this way, in the swirls of the river, basins are finally carved out of the solid rock. This is the history of the beautiful deep pools which occur in connexion with the falls.

In Norway, a country famous for its waterfalls, the pot-holes have been called "Giants' Kettles." Some of those best known to travellers occur in the "Glacier-Garden" of Lucerne in Switzerland, one of them being 26 feet wide and 30 feet deep.

Mr. H. J. Marten[1] has given us some interesting figures as to the rate at which pot-holes can be worked out in soft red sandstone, a rock familiar to dwellers in the midland counties of England. In 1844 a weir was built at Holt Fleet, where the Tenbury and Droitwich road crosses the valley of the Severn. In 1887 it was found that a number of the stones on the apron, or the slope of the weir facing down the stream, "had been drilled through and through by the action of the current upon small pebbles lodged either in hollows on their exposed surfaces or between the joints of the stones." The Severn, in this steeply banked and picturesque part of its course, brings over each square foot of the apron about 2000 gallons of water every minute, moving at a rate of 12 to 15 feet per second; and the current has

[1] "On Some Water-Worn and Pebble-Worn Stones taken from the Apron of the Holt-Fleet Weir on the River Severn," *Quart. Journ. Geol. Soc.*, vol. xlvii (1891) p. 63.

been known to move fair-sized boulders up the steep face of the weir and to push them over the crest and down the apron. Six stones, about 6 feet long, 2 feet broad, and 2 feet 6 inches thick, were specially examined by Mr. Marten, and it was shown that in forty-three years the eroding action of the stream had cut away about half their bulk, and had removed two inches of stone from the general surface of the weir. Of course the softer portions would go first; but it seems likely that in a hundred years these large stones would have been entirely destroyed.

It is now clear that a rushing stream, like that on our mountain-side, pushes along any loose stones that may fall into it, and can even move big boulders if the slope of the ground is steep enough. The rough stones grind against one another, and those of medium size soon have their corners knocked off, and finally become rolled into pebbles. But a very long journey down stream is required before the finer materials become well rounded, and many of the little grains of sand, which are easily washed apart from one another by the water, come out at the mouth of the river practically as sharp as when they fell into the water. A good deal of the sand is also produced by the grinding of one rock against another, and, as a rule, the smaller the fragments thus taken off, the less chance there is of their being made into true round pebbles.

Of course some materials of the earth rapidly go to pieces under this rough treatment, and hence the pebbles may not fairly represent all the different rocks that have fallen into the flowing stream. We may have only the harder and more resisting ones remaining, and some materials may be broken mechanically into fine powder, while others may actually become slowly dissolved away in the water. But here on our higher mountain-slopes the stones have not travelled far enough for any sorting out of the different kinds to have occurred. If there is a limestone or a shaly rock above us, we shall still find pieces of it lying in the streams, side by side with the hardest rocks, such as those composed of quartz.

If we watch long enough, particularly after rain, we shall see these pebbles and small stones actually moving. I remember, after a thunder-shower near Thun in Switzerland, how the lumps of rock, about the size of cricket-balls, came

rolling down a shallow streamlet as if they were being bowled down upon us from above. And we may now go a step further, and notice how the constant passage of stones and sand over a rock tends to cut a groove in it, just as a stone, when kept moving near one point, works out for itself a pot-hole. Hence the little gorges, which look like rents in the solid rock, have really been cut by the torrent, which uses such stone tools as are given to it; and in this highland region they are still being deepened as the waters rush down daily. Of course the water often begins by flowing down some real crack in the rock, which it soon widens with its tools; and thus you may see several gorges roughly parallel to one another in different parts of the stream, because the cracks or *joints* in the rock are parallel through a large part of the mountain. But in other places gorges will be cut, without this assistance, through the hardest and most uniform rock-masses, as neatly as if we were to divide a bar of soap by drawing a string in one direction steadily across it.

But where do the tools of the stream come from? How do they get into it? Or have all this sand and all these blocks of various sizes been lying about from time immemorial as a coating to the solid earth? We will let the grim crags above us answer these questions for themselves.

Suddenly we step across the last conspicuous ledge of rock and have quite a new landscape before our eyes. We see the source of our tempestuous little stream—a gloomy lake, stretching away towards a semicircle of cliffs, which tower almost vertically above it. Seen from this side, the water looks indigo or absolutely black; only when we walk round and look out towards the open lowlands do we catch some broad and gleaming reflection from the sky.

These mountain-tarns are among the most beautiful, and at the same time loneliest, things in nature. Sometimes, as you sit beside them, you will be almost startled by the mere sound of a stonechat upon the shore; in Scotland, or the west of Ireland, you may perhaps look up and see an eagle sweeping out from the gloom and blackness of the crags.

On the side of the lake farthest from the semicircle of cliffs, there is often a little beach of sand; even here the wind beats the lake up into waves and so manufactures pebbles on the shore. The place where the stream runs out

is often difficult to trace, since the water escapes among the tumbled blocks around the borders of the lake, and only collects as a stream lower down, through the union of several of its underground tricklings. Similar streamlets come down the walls of rock into the lake, and thus there is a constant current through it.

These higher streamlets descend in steep gullies; but at the foot of each there is a great loose mass of angular stones, forming a cone stretching up from the lake-shore towards the higher crags. Every groove of the rocks has a cone of this kind at its base; it is the simplest form of **talus**, the heap made by the materials that fall down into the hollow from above.

To understand these heaps, we must not be content with a clear summer's day when we climb up towards the summit of the mountain. We must visit the hollow in rough weather, when every groove is filled with a white line of foaming water, and when every stone shines with dampness and is ready to move easily over its neighbours. Then we may hear the clatter of sudden little slips of rock; we may see all round us the work of destruction going on; and we shall learn, indeed, that these cones of *débris* are continually being added to from above. The mere force of the rain driven by the wind, against which we can scarcely stand at these high levels, is sufficient to beat out tiny fragments from the crevices of the rocks, to widen these crevices year by year, and finally to set a large block rolling down the slope. When it once starts, it forms a powerful engine of destruction; it batters at projecting points in its passage, it sets perhaps a ton of material moving when it strikes upon the steeply piled talus; and thus it not only breaks up other rocks, but it helps the earlier products of decay to move lower down the mountain-side.

Every gusty wind that we know down in the valley is intensified at heights of two thousand feet and upwards into a destroying storm-blast. The air has few interruptions, and moves freely over long distances before it strikes upon the mountain-ridges; and there it gets suddenly checked, and goes roaring into every hollow, driving before it water, and sand, and even little loosened stones. As an example, we may note that the winds blow across Ben Nevis from November to March at an average rate of twenty-two miles

an hour, and between June and August at eleven miles an hour; but, 4400 feet lower, in the hollow of Loch Linnhe, they blow with rather less than half these velocities. During a south and south-west gale on February 21st and 22nd, 1885, the wind blew at the summit of Ben Nevis from the noon of one day to that of the next at about a hundred miles per hour, the velocity down below at the sea-level being only about thirty miles per hour.[1]

The vigour of the wind in buffeting the peaks of mountains may be further gathered from the fact that during the memorable storm of November 16th to 20th, 1893, the wind blew near the sea-level at Holyhead at eighty-five miles an hour for four hours together, and reached ninety-six miles an hour in the Orkney Isles.[2]

Even on ascending a church-tower, we notice an increase in the keenness and swiftness of the wind; and on the summit of the Eiffel Tower in Paris the velocity is three times greater than that experienced in the city, only 1000 feet below.[3]

Moreover, the air is far moister, and thus far more rain falls, on these higher levels of the hills. It always feels colder than in the plains below, although we are in reality, by ever so little, nearer to the sun; and observers in balloons tell us how soon they can ascend to a level where the temperature is below the freezing-point of water. The reason for this is that dry air is not heated directly by the luminous rays of the sun; these rays, however, warm the earth and the ocean, which in turn radiate "dark heat rays" to the air resting upon them. The air nearest the earth's surface is thus the warmest. But a cubic foot of warm air is lighter than a cubic foot of cold air —or, rather, in these great masses of the atmosphere, we should speak of millions of cubic feet; hence a disturbance of the balance of the atmosphere occurs where any locality becomes heated, the air expanding as it is warmed, and the colder denser air pressing in and forcing the warm air upwards. As the latter rises, it cools again, especially because it has now less of the atmosphere pressing upon it, and thus can expand greatly, its heat becoming spread over a far greater space than before. Hence the body of air at

[1] "Meteorology of Ben Nevis," *Trans. Roy. Soc. Edinburgh*, vol. xxxiv. (1890), pp. xxxvi., 164, 372, &c.

[2] C. Harding, *Nature*, vol. xlix. (1894), p. 295.

[3] A. Angot, *Comptes rendus*, vol. cix. (1889), p. 698.

a high level is characteristically colder than that in contact with the ground.

Then, again, evaporation goes on, as we all know, more freely in warm air than in cold; and the air near the earth absorbs into itself a large quantity of water in the invisible gaseous form. It does not soak it up like a sponge, for the particles of water-vapour, in becoming added to those of the mixed gases which constitute the air, merely introduce a lighter substance into the mixture and increase the bulk of the whole. Hence moist air is lighter, bulk for bulk, than dry air, and warm moist air is likely to rise most readily to the higher regions.

Air at any given temperature, however, can only absorb a certain quantity of water-vapour; it then has reached its *saturation-point*, and must yield up some of its water-vapour in the liquid form again directly it becomes cooled. It is scarcely necessary to mention here that this is the cause of the sheets of cloud above us on a gloomy day, or of isolated clouds at any time. **Clouds** result from bodies of moist air becoming cooled below their saturation-point; the water separates out around the floating dust-particles of the atmosphere in the form of tiny drops, which are so small as to be wafted along without falling to the earth. At last, however, continued cooling may produce a rain-shower, when the minute drops have run together into larger ones, and can no longer be buoyed up.

The level at which clouds can be formed will vary with local conditions of climate, and with daily changes of temperature on the earth itself; but a level must exist in the atmosphere, above every locality, where the temperature is below the freezing-point of water, and where any moisture separated from the air must take the solid form. At this level the delicate *cirrus-clouds*, or "horse-tails," are formed, which consist of masses of snow-crystals supported by the air-currents; in our winter-time, gloomy and denser snow-clouds may arise close to the surface of the ground; in summer the light cirrus may be four or five miles above our heads. The level in the atmosphere above which, even in summer, the temperature remains always below the freezing-point of water (0° C. or 32° F.) may be called the **snow-level**. The snow-levels of different localities, when traced from one point to another, form a surface which now approaches, now

recedes from, the surface of the ground; and, if any parts of the earth are sufficiently elevated to rise through and above this "snow-surface," the line formed on them by the local snow-level will be what is called the **snow-line.**

Sometimes, when the accumulation in winter is very great, snow may lie at levels where the average temperature of the year is as high as 3° C;[1] but, in all ordinary cases, when we rise above the snow-line, dew cannot be deposited nor can rain fall, even in the height of summer. Their places are naturally taken by hoar-frost and snow. Evaporation goes on from the surface of the snow, despite the cold, provided that dry air is brought into contact with it; but the chances are in favour of continual deposition of fresh material—we have here, indeed, a region of perpetual snow.

Now, our British and Irish mountains are not so high as to reach above the local snow-line; but again and again we can observe how their summits are in the level of the clouds, while the valley below is warm and free from mist. As we sit by our little lake and look upwards, we notice wisps of cloud even now forming among the rocks, particularly on the shaded side of the mountain; soon they are blown away into warmer and drier regions of the air, and disappear again in a gaseous form. But, as night comes on, clouds will gather all along the ridge; the earth no longer warms the air down in the plains and sends hot supplies up to the mountain-tops; the cloud-level drops lower, and the more prominent peaks stand out clearly above it. A moonlit night is best for observing this effect, for then the earth cools rapidly into the clear air, and the long banks of cloud lie still and white against the hills.

The ridges are liable to be cloud-capped at any time, particularly if the prevalent winds bear moist air with them from the sea. This air, already near its saturation-point, comes against the hills, and is forced to move towards higher levels in order to pass over them. In so doing, it becomes chilled below its saturation-point; the moisture comes out of it as a sheet of cloud, one edge of which rests against the mountain; and above this the sky is clear, since the air has been thus rendered dry again, though it is even colder than at the level of the clouds. As long as the same wind blows, bringing in the moist air against the mountain, the clouds

[1] Heim, "Handbuch der Gletscherkunde," p. 110.

will go on accumulating; and at last they themselves become driven bodily up the slopes and over the crest into the drier area beyond. Here, like the little wisps we were watching among the crags, they become absorbed again, and the whole mass of cloud may thus be continually added to at one end and dissolved away again at the other. It will probably not be long, however, before further chilling causes the cloud-drops to run together, and copious rain to fall upon the windward slope.

Then, on the clear and cloudless nights, **dew** is freely deposited on the mountain. The air is often near its saturation-point at these high levels, while radiation of heat from the rocks and grass is bringing their temperature steadily down. Then the film of air in contact with them becomes also cooled, and finally yields up its moisture in little dewy beads, which accumulate rapidly if the air is in motion, and if fresh material is thus brought to the cold surfaces. If the saturation-point of the air is lower than the freezing-point of water, the water-particles may be extracted from the air in the form of delicate ice-crystals, or **hoar-frost.**

One of the most beautiful sights upon a mountain is when every projecting point of rock and every blade of grass is tipped with hoar-frost streamers; it becomes clear that we are not dealing in any way with frozen dew, but that the ice-crystals have been deposited as such out of the atmosphere, accumulating one on another, the ice-banner sometimes pointing in the teeth of the wind, and sometimes curving in long plumes in the opposite direction. I have seen the upper thousand feet of the Mourne Mountains covered with hoar-frost of this kind, so that the accumulation of it during two days finally resembled snow. On Ben Nevis, with the ordinary wind-rate and cold fogs, these crystalline plumes grow as rapidly as half-an-inch per hour.

If all the moisture deposited in one form or another out of the atmosphere, at any place during an average year, were converted into a sheet of water lying on the level surface of the ground, just where it fell, none of it being evaporated again or allowed to run away, then the depth of that accumulation of water, measured in inches, is what is styled the mean annual **rainfall.** Observers at fixed stations collect the moisture—dew, rain, hoar-frost, or snow—daily in *rain-gauges*, and carry on their records month by month and year

by year. Thus in time they arrive at a correct average statement of the rainfall, which is expressed in inches, the hoar-frost and snow being calculated as if melted. Here, again, we will take a special instance, showing how the rainfall is greater at high levels, especially where the prevalent winds blow from large bodies of water towards the hills. On the summit of Ben Nevis, 4406 feet above the sea, the annual rainfall is 129.5 inches; but below, at Fort William, 29 feet above the sea, it is only 77.3 inches. That is still a high rainfall for the British Isles, the eastern counties of England having only about 24 inches.

We are now in a position to realise that the summits of our mountains are kept continually damp by dew, which soaks into every crevice, and which actually helps to feed the streams. Clouds are continually moving over the surface, and rain falls far more abundantly than in the plain below. The blasts of wind are here felt in all their force; it is, in fact, a region of violence and storm. Besides the mere battering of rain and hail, all this moisture exerts a powerful chemical action. Rain, while falling, dissolves the gases of the air, and in proportions very different from those in which they are mingled in the atmosphere. While in 100 cubic feet of the latter we have 21 cubic feet of oxygen and 79 of nitrogen, rain-water may absorb 35 parts by volume of oxygen to 65 of nitrogen. Iron is common in various combinations in the rocks, and the oxygen, carried downwards by the soaking water, tends to make hydrated iron oxides along every joint and surface. The brown stains of rust that result are the signs of extensive chemical decay. The carbon dioxide, also absorbed in larger proportion than that in which it exists among the gases of the air, slowly attacks the compound minerals, making carbonates out of some of their constituents; and these carbonates are often soluble, and are carried away with the general flow into the streams. Complex silicates like felspar become thus broken up, the soda and potash disappearing as carbonates or silicates in solution, some silica being set free, which also passes into solution, and the aluminium silicate combining with water and forming a soft white powder known as kaolin (p. 21). When one mineral of a rock breaks down in this way, and is carried away, either in solution or in solid particles, the whole rock soon becomes loose and crumbling, and the minerals that could not be

attacked by natural waters are set free as little grains, to be washed or blown down the mountain-side. By insidious action such as this, huge masses of rock are eaten into, and the storms are always clearing away the detritus and exposing a new surface to attack.

Limestones are bodily dissolved by rain-water containing carbon dioxide, and we find their surfaces covered with little pits and circular hollows. We may often recognise them in this way among the other rocks of a hillside; and in some parts of the Alps they are eaten into by the storm-water, until the grooves so made resemble gigantic saw-cuts.

For the grandest insight, however, into the assaults of weather upon the mountain, we must come up into our highland-hollow after a clear cold night. During the day all the cracks of the rocks have been filled with water, which has become frozen during the hours of darkness. As water cools, it contracts in bulk until it reaches 4° C.,[1] after which it expands again. At 0° C., the freezing-point, it passes into the solid state, and a given bulk actually occupies a space rather more than an eleventh greater than that which it occupied at 4° C. Moreover, the great part of this expansion occurs suddenly, at the moment of solidification, and thus the water imprisoned in a crevice has no time to ooze out again, but exerts a splitting force upon the rock in which it is confined.

It will be well to have this stated exactly. 100 grammes of water at 4° C. occupy a space of 100 cubic centimetres; at 0° C. this bulk of water has increased to 100.012 cubic centimetres; but at the same temperature it becomes ice occupying as much space as 108.992 cc. Another way of stating the matter is that 91.75 cubic inches of water at 0° C. pass abruptly into 100 cubic inches of ice.

As the sun strikes upon the mountain and heats the rocks again, the ice melts, and huge fragments, which have thus become wedged out, are dislodged from the cliffs above our lake. **Frozen water** has thus a startling effect in breaking up a mountain-mass. Day after day it may work in this way, and may shower down stones large and small on to the growing talus-cones. The whole mountain is, in fact, decaying, and it is being attacked most vehemently

[1] Or a temperature very near to 4° C.; M. de Coppet gives 3.982° C. (*Nature*, vol. li (1894), p. 37).

in its higher levels. The stones and gravel that we saw on the ascent have all been worn from it by rain and frost and slow insidious chemical action. The lower slopes become protected by the showers of *débris;* but the streams wash down through these, and use the loose stones as tools to cut deep channels in the mountain-flanks. In our hollow itself, around the little lake, we can see how the agents of decay continually lay bare new surfaces; and we say that rapid **denudation** is going on.

Thus, then, we can account for the steepness of the crags towards the mountain-crest. The denudation is violent, vertical in its character; and the result is all the picturesque scenery of peak and notch and gully that makes the ridge at sunset look like a black saw against the sky. Our semicircular hollow has been cut back on a large scale, like the little **alcoves** over which the waterfalls of the stream descend (Plate I). One line of weakness, one principal groove where the water rushes down at every storm, has determined the main recess; numerous side-streams have done their work, and the frost has split off block after block and kept the walls almost vertical. For a long time the scour of water at the foot was probably sufficient to prevent the *débris* from forming banks against the cliff; and the hollow of the lake itself may be regarded as resulting from this vehement swirling action. It is, in fact, an exaggerated pot-hole, and corresponds, in a broad form, to the basins beneath the waterfalls in the stream. Another agent, which we shall refer to later, has probably helped to keep the hollow clear (p. 56).

Our mountain-hollow may be called a *combe,* the nearest English word for the Welsh *cwm,* which is applied to similar rock-bound excavations. But the most international word is **cirque,** which is used to express the form of the cliff, reminding one of half a Roman circus. When, by continued weathering-back, two cirques approach one another on opposite sides of a mountain-mass, the ridge between grows narrower and narrower, until at last it may be a mere knife-edge, accessible only to skilful mountaineers. Splendid examples of cirques occur on Snowdon, the ridge or **arête** between Cwm-y-Clogwyn and Cwm-y-Llan, where the Beddgelert path runs up, being only eight feet wide; while the sawlike crest of the Crib-Goch, between Cwm-Dyli and

WATERFALL FORMING AN ALCOVE IN STRATIFIED ROCKS, GLENCAR, CO. SLIGO.

PLATE I.] [*Photographed by* Mr. R. WELCH.

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Cwm-Glas, is considered good exercise for members of the Alpine Club.

Above us still, in our mountain-hollow, we can see a number of pinnacles standing out against the sky. They are the masses left behind by the little streams, which have cut deep grooves on either side and have in part hollowed away the rock behind them. Small as they look from below, they tower above us when we clamber up among them; some look as if they must speedily be undermined, and all are no doubt decaying. Yet the changes that go on here are slow, and the oldest inhabitant of the hillside-farms will say that these fantastic rocks have "always" been just as they are now.

Well, we must admit that in the British Isles denudation on the mountains is, after all, a comparatively gentle matter. Come to the summit of our ridge, sit on the pile of stones which the Ordnance Survey has heaped up as a landmark, and look out over the general landscape. Peak after peak rises from the highland country near us, but the lower slopes are thickly strewn with *débris* which the streams are unable to carry off. The great times of carving and excavation are at present over, and we are apt to think that some agent more violent than those which we see at work around us first made these giant channels between the hills, and then flung down the huge boulders into them.

But the fact is that we have come too late to see our mountains in their fullest grandeur. The vast piles of detritus, the long sweeping taluses, show how much dignity they have lost. Many summits in Scotland, like those of Ben Nevis or Quinag, are actually buried in loose blocks, so that we have to go lower down to see the solid rock exposed. Our mountains have been worn down until they have come below the level of most vehement attack; to study denudation in all its real rapidity, we must scale another six or seven thousand feet, in the Pyrenees, Norway, or the Alps.

Here matters become more complicated, for we rise above the snow-line. On the upper parts of these huge mountains all moisture will be deposited as snow and hoar-frost. Here and there the bare rocks may get heated by the sun, may melt the snow in their crevices, and may be broken up by the expansion of the water as it freezes again later in the day; but the main mass of snow will go on accumulating, slipping off the steeper crags and gathering

thickly in the hollows, forming there broad **snowfields**, from which it is removed in two ways — by the formation of *avalanches* and by *glaciers*.

Many crags upon high mountains are so sheer that the snow can lie only upon occasional little ledges. Of such a character are the great face of the Matterhorn, and, still more strikingly, the huge conical and spire-like pinnacles, the *Aiguilles* of both flanks of Mont Blanc. In other peaks there may be a long steep slope where snow gathers, but from which any great accumulation must tend to slip. The sides of the huge Alpine valleys similarly offer very little resting-ground for snow. A crack forms in the surface of the steeply lying snowfield, and any trifling disturbance starts the great detached mass down the slope. Carrying with it stones and earth and lumps of ice, these last resulting from the compression of the lower layers of the snowfield, it plunges headlong into the valley as an **avalanche**.

Dr. Pernter[1] of Vienna has given us an account of the avalanches in the range of the Hohe Tauern, on the borders of Karinthia. It appears that some are caused by the partial melting of the snow-sheets by the warm south wind; gradually the water accumulates, and diminishes the friction of the ground against the lower surface, which has hitherto upheld the mass; and finally the whole sheet slides disastrously downwards. Other avalanches are caused by the slipping of newly fallen layers over previously consolidated older ones. Their movement is very rapid, and they are preceded by a terrific blast of air. One such avalanche witnessed by Dr. Pernter filled a valley "for a distance of two kilometres with thirteen feet of snow. The avalanche itself could not force its way up the side of the opposite mountain, but the wind caused by it unroofed a farm-house, 650 feet above the valley, and blew in the windows."

The prevalence of avalanches, as a means by which the accumulation of winter snow, and of snow above the snow-line, is got rid of, causes certain mountain-pathways to be very dangerous in the spring. In many cases the magnificent roads constructed in the Alps about the close of the Napoleonic wars run at higher levels than the old mule-tracks, so as to be above the lines along which the avalanches

[1] "A Winter Expedition to the Sonnblick," *Nature*, vol. xlii. (1890), p. 273; also Dr. M. Ogilvie, *Nature*, vol. lii. p. 573, on the Gemmi avalanche of 1895.

are likely to break off from the main snow-sheet. This is notably the case with the Splügen road, which proceeds at first almost horizontally from the pass, and then descends by a bold series of curves and tunnels cut in the great cliff above Isola. It thus avoids the steep-sided valley which Marshal Macdonald traversed with so much difficulty in the winter of 1800. Avalanche-galleries, to protect travellers, are common at exposed points on any mountain-road.

The snow may accumulate at high levels to depths of 50 to 90 metres (160 to 300 feet), and the lower layers in the gathering-grounds or snowfields become, as we have hinted, greatly compressed and compacted, and, in fact, converted into ordinary massive ice. We must remember that this results in no way from a further freezing of the snow; the term "frozen snow," which is sometimes seen in newspapers, has strictly no meaning, since all snow consists of ice-particles and cannot be more frozen than it is at the time of its formation. But it can have the air squeezed out from between the crystals, as occurs when a good hard snowball is constructed; and this is what happens to the older snow of a snowfield as the newer layers press steadily upon it.

At first, under these newer layers, we have a snow that is firmer, and in which the ice-crystals are compacted together into groups, forming little granular lumps, partly transparent, partly white with air-bubbles. This material is known to German-speaking mountaineers as **firn**, and to the French as **névé**. As the surface-snow melts in the sun, water trickles in between the granules of the firn, freezes there, and surrounds them with a cement of ice; the mass thus caused has been called *firn-ice*.

Continued pressure forces nearly all the remaining air out of this firn-ice, and a compact layer of ice results. The massive ice that is made in this way consists of a number of granules from two millimetres to fifteen centimetres[1] in diameter, each being composed of one ice-crystal. The largest ones occur in the ends of the ice-streams or glaciers, and a good average size for these *glacier-grains* is that of a walnut. They fit perfectly into one another, but the surfaces

[1] J. C. McConnel and D. A. Kidd, "On the Plasticity of Glacier and other Ice," *Proc. Royal Soc. Lond.*, vol. xliv (1888), p. 333; and A. Heim, "Handbuch der Gletscherkunde," p. 120.

between them can be seen as the ice slowly melts away in lower levels of the mountains.

This massive ice becomes squeezed out under the snow-fields, and oozes slowly down the hollows of the mountains in the form of ice-rivers or **Glaciers**. At the lower end each glacier is melted away, at the upper it is continually supplied with fresh snow; and thus it keeps in much the same position on the hillside. But throughout its length the ice is moving forward, as has been shown by the changes in the position of stones lying on its surface, and by driving stakes into the ice and noticing that they are carried down the slope. If a row of such stakes is set up along a line across the glacier, it will soon be found that the central ones have moved farther than those nearer to the sides. The rate of movement is about 4 to 16 inches a day, 1 foot per day being a fair average, measurements from the Alps, Norway, and the Himálayas agreeing closely. Far more rapid movements have been recorded from northern regions, but it now seems that even the Muir Glacier of Alaska, an unusually swift example, progresses at only 7 feet per day.[1] The flow is more rapid towards the centre of the stream, because the ice there is not retarded by the rocky walls of the valley; the central portion flows, indeed, from three to ten times as fast as the margins. Similarly, the upper layers of a glacier move more quickly than those that rest against the valley-floor. The partial melting that takes place in summer also considerably assists the flow, especially in the case of a small glacier. Again, where the valley is narrow, or where the floor falls steeply, the glacier moves more rapidly than in its broader or more gently shelving portions.

Some glaciers are mere small patches of ice oozing out from the edge of a high snowfield, and falling from time to time over the great cliff below in a series of dangerous avalanches. Sometimes a glacier of this kind gives rise to a new one in the hollow below, where the blocks of ice become compressed together again and ooze downwards as before. Many glaciers, apparently hanging on the mountain-side, covered with grey dust blown on to them from the rocky walls, are by no means imposing features in the

[1] H. F. Reid, "Studies of the Muir Glacier." See *Geol. Mag.*, 1892, p. 429.

landscape, and look mean and dirty after the pure white snows above. But a really large glacier is often a magnificent spectacle. As it comes round corners of the valley in which it descends, it cracks open in a series of deep *crevasses*; the rich blue ice is seen in their walls, and between them the surface of the glacier is rugged, broken, and serrated. When a steep place in the valley is reached, an *ice-fall* occurs, the glacier breaking into huge blocks and reuniting down below. Here again one can see all the beautiful colour of the ice, the pile of angular masses towering up the slope like a vast stairway shattered by an earthquake, and gleaming white, or coldest blue, or green, in the brilliance of an Alpine sun. On the Furka Pass, to take a fine example, we may toil up a long bleak valley from Andermatt, and then suddenly come out in view of one of the most impressive sights in Switzerland, the ice-fall of the glacier of the Rhône. We might wait some time before we could notice a change in the positions of these freshly broken masses; but the ice is here descending at a comparatively rapid rate, and the glacier is completely torn to pieces.

At its foot, the glacier, where the floor of the valley is wide and flat, spreads out like a thick fan, with crevasses running from the semicircular margin towards the centre of the ice-stream. Often a glacier melts away on the steeper slope of the mountain, and ends off in a somewhat narrow and irregular tongue. A cave occurs in any case in the foot of the ice, where a stream, white with sand and mud, runs swiftly out. This stream has arisen under the ice far up the slope, partly from the melting of the lower layers by the warm earth, partly from the trickling in of water from the upper layers as they are melted by the sun, and partly from streamlets which have fallen upon the glacier in regions below the snow-line, and which have found their way to its base down the crevasses.

The final complete melting of the ice at the foot of the glacier adds largely to this stream, and a considerable flow of water is the result. The Rhine and the Rhône, for instance, both arise thus in the glaciers of central Switzerland.

We have said that the foot of the glacier remains fairly stationary. It certainly does not move forward, ploughing

up the land and menacing the peasant with destruction, as is often stated in imaginative answers written in the excitement of examinations; but in certain times of heavy snowfall the lower edge of the glacier advances steadily; then in other years it recedes up the slope, as the mass becomes melted more quickly than the snow is supplied to it above. Observations tend to show that in Switzerland the glaciers advance and retreat again in a period of from thirty-five to fifty years, and that there has been a steady increase in the length of several since 1875.[1] Of course changes in climate, extending over far longer periods, may also be going on, and may ultimately tend to increase or to reduce the glaciers in a very striking manner.

Even under existing conditions of climate, and in warm countries, glaciers are impressive in their extent. The Great Aletsch glacier, in the Bernese Oberland, the largest in Switzerland, is fifteen miles (24 km.) long, and in most places is a mile across. In the Himálayas, moreover, where the snow-line lies as high as 16,000 feet, some glaciers are thirty-five miles in length.

The thickness of the ice has been measured by soundings in the depths of the crevasses, and Professor Heim[2] concludes that the Alpine glaciers are commonly from 200 to 400 metres thick—let us say, 1000 feet.

The more we consider these enormous masses of ice, the more interesting does their movement seem. The precise causes of it have been the subject of many disquisitions; briefly, we may say that the granular character of glacier-ice seems the most important point to be kept in view. All these irregularly bounded crystals, fitting closely into one another, are capable, under pressure, of rolling over and altering their relative positions. Some become, under specially favourable conditions,[3] frozen together to form a single larger grain; but the whole glacier-mass moves forward, into hollows and round corners, as a plastic body. Any piece of ice, moreover, is composed of one or more crystals of solidified water; and each separate crystal is capable of altering its form when stress

[1] F. A. Forel, *Nature*, vol. xlvi (1892), p. 386.
[2] "Handbuch der Gletscherkunde," p. 79.
[3] See the interesting experiments of Heim, *Ibid.*, p. 330.

is applied to it.[1] Thus, if a bar of ice consisting of one crystal is supported at the two ends, while a weight is hung by a string from its centre, the ice will bend down into a curved form. This plasticity of the individual glacier-grain has only recently been brought forward as a cause of glacier-motion; but it is easy to see how it may help the whole glacier to fit itself into the irregularities of the ground. The phenomenon of the uniting of two surfaces of ice when pressed together is discussed, under the title *regelation*, in all text-books of Physics, and, with notable clearness, in Tyndall's "Forms of Water." Ice becomes liquid under pressure; the water formed spreads out over the surfaces that are being squeezed together; and, the moment that the pressure is relieved, this water becomes solid again and cements the two blocks together. Thus ice broken by crevasses and on ice-falls will reunite into a granular plastic mass, the required relief from pressure being afforded by the onward movement of the whole.

This movement of the glaciers enables them to play a most important part in the denudation of high mountains. We have already seen how some glaciers look dull grey or brown upon the surface, owing to the immense quantity of dust and small stones that are dropped upon them. But in addition there is at each side a line of far larger blocks, which have fallen upon the glacier from the rocky walls of the valley in which it is descending. Frost wedges off these blocks in the upper regions, and sometimes torrents add material in the lower part of the glacier's course; but the blocks, however huge, are carried downwards by the steady flow of the ice, and the valley-walls above the glacier cannot become banked up and protected by the products of their own decay. The lines of stones thus produced are called **lateral moraines**. All the material carried by the glacier is, of course, dropped at the end as it melts away, and there forms a great loose deposit known as the **terminal moraine**.

If we visit the foot of a glacier soon after sunrise, we shall see the stones falling over the great ice-slope and

[1] J. C. McConnel, "On the Plasticity of an Ice-Crystal," *Proc. Royal Soc. London*, vol. xlix, p. 325; Emden, "Ueber das Gletscherkorn," *Nouv. Mém. Soc. Helvétique des Sci. Nat.*, tome xxxiii (1893), p. 1.

bounding down into the stream as it flows out below. All through the night these stones have been thrust farther and farther towards the edge, and now the sun is just warming them, loosening the grip that the ice has upon them, and allowing them to fall in quite an abundant shower. At all times of the day some blocks or other are about to drop over the edge, but we may not be so lucky as to catch them precisely in the act.

The terminal moraine is undermined and spread out by the rush of the stream, and forms a huge bank of boulders, pebbles, and sand, stretching away into the open valley. Wherever glaciers are at present smaller than they have been in the past, we see the old lateral moraines, like the walls of some ancient fortification, on either side of us; the ice-mass has shrunk and narrowed, and has left these stone-ridges behind it. At the same time the terminal moraine will, as the ice retreats, stretch back farther and farther up the slope. In the glaciers descending from Mont Blanc, towards both Chamonix and Courmayeur, the stranded lateral moraines form very conspicuous features.

Medial moraines also occur; these are lines of stones running down the length of the glacier at a distance from the valley-walls. They are easily traceable to the place where two glaciers join one another in the higher regions; here two lateral moraines meet, and are carried on together as a single medial moraine. Wherever the glacier, moreover, breaks against a prominence of rock, and flows round it on either side, uniting again below, a medial moraine is likely to be formed; so that sometimes seven or eight lines of *débris* may be seen running down the length of a great glacier. The work done by ice in this way as a carrier is greater than that of any other agent; blocks as large as houses can be conveyed many miles from their parent source and deposited as mysterious strangers in the great terminal moraine.

In some countries the snow-line is so low, or the accumulation of snow in some mountain-hollows is so great, that glaciers are able to descend to the level of the sea. Then there is, properly speaking, no terminal moraine; the end of the glacier, continually pushed forward into the sea, becomes floated up, since ice is lighter than water; the crevasses become filled with the moving water, and huge masses of ice are broken off as **icebergs**. They go floating away upon the

ocean-currents, carrying their load of *débris* from the land, until they are at last melted in warmer waters. If there is a regular drift of icebergs in a particular direction, towards a latitude where they all become melted away, a sort of scattered terminal moraine occurs there, forming a vast bank beneath the sea. A deposit of this kind is being produced in the Atlantic Ocean, where the land-ice borne on the Labrador current meets the warmer waters from the south. Floating ice, then, carries coarse materials to far more remarkable distances than any ordinary glacier. Whether borne by a glacier or by floating ice, boulders deposited in a distant area are styled, from their wandering character, **erratics.**

There is no wonder that the streams rushing out through the terminal moraines of glaciers are white with mud and sand. But, if we enter the ice-cave, we shall see that the stream is already muddy when it issues from the glacier; the material carried along by it must have been gathered farther up the slope. As a matter of fact, the crevasses of glaciers allow of numerous stones falling to the bottom of the ice; there they become held in it, and serve as formidable tools for cutting into the rocks below. The fine dust and sand, in part falling from above, in part produced by this cutting action, works like sand-paper in smoothing the floor over which the glacier moves. These materials, accumulated in and beneath the glacier, have been styled the **ground-moraine.** Wherever glaciers have shrunk, or have sunk farther into the valley that is continually being deepened under them, we see the smoothed rocks left behind to bear witness to this scouring action. Some rocks, such as limestones, take a polish from the passage of glaciers over them; others, such as granites, are only ground down to a broad clean curving surface; sharp scratches occur in these surfaces, and sometimes also coarser grooves, where the larger stones have cut into the more uniform work of the fine sand. Rocks that have been treated in this way are said to have suffered from glaciation, or to have been *glaciated.*

The tendency of such grinding action is to smooth off and round every angle of an obstacle beneath the glacier, such as a projecting mass of rock in the valley-floor; but the front of any rock which faces down the valley will be left fairly rugged, though the glacier grinds away the back into

something like a dome. A series of such rocks, when revealed to us by the retreat of the glacier, will give a hummocky appearance to the valley; on going up towards the glacier, we see merely the rugged ends of these bosses; on looking down the valley, all their smoothed and rounded surfaces are exposed to us. Such glaciated rocks are called **roches moutonnées**; and it is often said that this is due to their resemblance to a flock of sheep lying down. This, however, is an error, since *moutonné* means "frizzled like a wig." De Saussure,[1] who first applied the term, says that the rounded rocks look like a well-dressed fleece, or one of the wigs styled in his day *moutonnées*.

When we see whole mountain-walls smoothed over in this way, and the floor of a valley for miles carved into *roches moutonnées*, we are apt to get an exaggerated notion of the powers of glaciers as agents of excavation. As a matter of fact, the valley is constantly being deepened by the swirling action of the streams beneath a glacier, and every new surface exposed is promptly scoured smooth by the stones held in the ice. But it appears that the ice itself is so plastic that the upper layers of a glacier will move over the lower ones, if the latter encounter a serious obstacle; and hence the glacier itself is probably not a more gigantic agent than an ordinary mountain-torrent in cutting out a valley-groove. But the special feature of glacier-action is that the ice removes on its back, or included in it, so much *débris* which otherwise would cumber the mountain-side; it keeps the upper precipices always clear, always exposed to the renewed attacks of frost. Glaciers thus largely assist that vertical form of denuding action which we have seen to be characteristic of the higher regions of the mountain.

Huge pot-holes may in places be excavated beneath glaciers, by the cascades of water derived from the melting of the upper surface of the ice. These waterfalls go thundering down into the crevasses, and are kept sometimes steadily at work, the crevasse continuing to open at the same point of the valley, despite the onward flow of the glacier. They gradually cut shafts for themselves, down which they pour, and which are known as *moulins*, or *glacier-mills*. The rush of water thus beats upon any loose stones below and carves out holes and basins. The shifting of the *moulin*, which often occurs, as it cuts its way back in the ice, may in time produce consider-

[1] "Voyages dans les Alpes" (1804), tome ii. p. 435.

able basin-like depressions in the glacier-floor, the surface of these hollows becoming striated and polished by the action of the ice which enters them.[1]

When the ice diminishes, the work of these mills is revealed to us, as in the Gletschergarten of Lucerne (p. 32). Moreover, the larger rocks borne by the glacier are often left stranded in strange positions on the mountain-sides. The finer material of the moraines may eventually be washed away, and these **perched blocks** remain conspicuously overlooking the present valley. Perched blocks are often thus seen resting on the backs of *roches moutonnées*.

Finally, the terminal moraine must in part consist of the stones and sand that have become included in the glacier and are extruded as it melts. Many of the stones will be strongly scratched and striated, often in several directions, as they are turned round and round under the ice. Where the glacier descends to the sea-level, they may remain stuck into the base of the icebergs, and become floated away into regions far removed from glaciation.

So much for our excursion into the higher regions of the earth. We may now be convinced of the truth of our observation on our own mountains, viz., that denudation is far more rapid, more serious, more precipitous in its effects, near the summits than on the valley-sides. The pinnacles that loom above us as we look up from the shore of our little tarn are models, as it were, of the *aiguilles* of Mont Blanc, or even of great mountain-peaks like the Grivola or the Matterhorn. When, after a sudden shower, we hear the stones rolling down the gullies and scattering upon the fan-like talus, we can form some notion of the constant crash of ice-loosened blocks into the glacier-valleys of the Alps. No lecture in geology was ever so impressive to me as a few words of Mr. W. F. Donkin, describing how he and his companions camped one night in a hollow under the ridges of Mont Blanc, and watched a huge rock leaping down towards them, tracing its course by the showers of sparks that it drove out of the granite wall. The fallen blocks upon our own slopes point to action almost as violent; witness the superb masses in the Pass of Llanberis, which, though their fall is now luckily rare, are fully Alpine in their grandeur.

[1] See T. D. La Touche, "The Erosion of Rock-Basins," *Nature*, vol. xlix (1893), p. 40.

But is there no other resemblance between our mountain-hollow and the Alps? Look carefully at the outlines of the rocks that lie between the wall of crags and the steep descent into the valley. The floor of the hollow itself, unless the taluses have crept too far across it, and the numerous swelling bosses of rock within it, are wonderfully smoothed. The outer rim of the lakelet shows the same rounding and smoothing; and here and there, on the descending slope, we look down on the bare back of a dome-like rock, only partially invaded by the damp green moss. Surely there is a meaning in these curving outlines. (See frontispiece.)

The dome-like rock faces down the slope as a steep little crag, in contrast to the smoothness that it shows upon the side towards us. Surely we have here the features of an old glacier-floor, with veritable *roches moutonnées*.

If so, we may well look further. There are suspicious groovings on the rocks nearest to us; but these may have been caused by the constant run of small stones over them during storms. But turn back the thin covering of grass and moss from one of the more protected surfaces; here we find cuts and scratches, mostly running in one direction, beautifully preserved, and unmistakable as signs of glaciation.

It will be worth while now to go down to the stream again, where it has carved a section in the gravel of the slope, and to see if any of the loose stones have scratches on them, as if they had come out from beneath a glacier. We may have to search for a long time, since much of this broad talus is of fairly modern origin; but in spots where the materials are slate or limestone, or any rock likely to receive scratches easily and yet not to be broken up into powder, we may be rewarded by a rich find of **striated stones**. Sometimes, under a mere superficial coating of fallen blocks, we may come upon a true terminal moraine, with great masses dropped from the surface of the glacier and scratched stones thrust out from below. These marked stones will often be the first things to reveal to us the former presence of glaciers in the district which we are examining. Such stones may have been floated hither in the base of icebergs when the present land lay beneath the sea; but, when we find them in conjunction with striated surfaces of solid rock, and with *roches moutonnées* pointing in a fairly uniform

direction, we may be sure that we are actually standing in the track of an ancient glacier.

It is only in the last fifty or sixty years that the meaning of such striated surfaces has been known to us. Even in Switzerland, when De Saussure wrote his famous "Voyages dans les Alpes," they were not connected in the minds of observers with the former extension of the glaciers. But now, thanks to Agassiz, Forbes, Ramsay, and other writers, we have been taught that vast areas of our British Isles were at one time covered with moving ice. How much of our glacial deposits were laid down on dry land, or how much in seas in which floating ice abounded, is still a matter for discussion; but again and again the smoothed rocks and *roches moutonnées* show that genuine glaciers were at work.

Indeed, most of our mountain-hollows have been glaciated. The Snowdon district provides us with admirable examples, conspicuous among them being the lonely hollow of Cwm-glas (see frontispiece), into which we can ascend from the centre of the Pass of Llanberis. There is a light bridge leading to a farm across the stream, and then we go up to a huge round-backed rock, the steep end of which faces down towards us. This is the great *roche moutonnée* of the lower portion of the cwm. The loose blocks around, and in the soil beneath us, are part of the local moraine, and are mingled with those left by the greater glacier that once swept down the pass. In those days the craggy walls were doubtless far higher, as may be judged from the enormous *débris* on the slopes; and above them were hollows full of *névé* leading up to the snow-peaks of the central mass. We may now pass round the great *roche moutonnée*, noticing the perched blocks upon other similar mammillated masses which project out below us towards the road. Somewhere in the left-hand curve of the cliff that now faces us, we shall find a steep passage leading into the upper cwm; and by this we can ascend to two desolate little lakes. In the height of the tourist-season, when hundreds of visitors stand daily on the crest of Snowdon, Cwm-glas remains one of the noblest and loneliest spots in Wales. The road is lost sight of some 1500 feet below; the precipitous semicircle of crags, ranging round us from Crib-Goch, forms a gloomy and often cloud-capped background; and the grey floor of the cwm, with its two sunless little lakes, lies strangely bare beneath us, completely smoothed by glacial action.

But similar hollows abound in the uplands of North Wales; the corries of the Scotch highlands, as we may note again and again, have been moulded and finished off by glacier-ice; and the pale quartz-hills of Connemara, the granite chain of Leinster, and the Reeks of Kerry, all give evidence, by their striated surfaces, of recent glaciers in our islands. Near Finchley, in the north of London, scratched lumps of hard chalk and other stones, with rubbed fossils carried from a distance, are found freely in the brickyard-clays. Near Dublin, the hollows of the granite mountains, and all the surface-gravels of the county, are full of limestone pebbles, exquisitely scratched by glacial action. Upper Lough Bray, a favourite resort in the Wicklow highlands, is closed on the higher side by the characteristic cirque of precipitous rock, and is banked up on the lower side by a coarse terminal moraine. The schistose hills, again, beyond Lough Tay farther to the east, are strewn with huge erratics of granite carried from the central range. The assistance given by ice to the formation of cirques may be realised in the higher Alps of Switzerland. Here frost-action and the battering of mountain-winds are the active agents in cutting back the walls of rock, and vertical cliffs of semicircular form result, whenever one part gives way more readily than another. But the snow that falls so freely slips down these precipices and gathers at their foot; any snow that manages for a few days to cling to the wall finally slides into the hollow, carrying loosened stones with it and helping to cut grooves in the rock-face. At the base of the cirque, in what seems an absurdly limited space, a glacier is formed, which flows out at the open side in a steep ice-fall. The blocks torn off by denudation become swallowed up in the snow on the surface of the glacier, and only a few enter the hollow itself down the crevasses; the ice thus protects the hollow, keeps it clear, and smooths and striates its floor. In one of the superb photographs taken by the late Mr. W. F. Donkin (Plate II), we see such a cirque at the base of the peak of the Matterhorn; and it is, as it were, a vivid restoration of the former condition of our British mountain-hollows. Were the little glacier to melt away, a tarn would be left, with a striated floor, beneath the grim theatre of the cliffs, like those of Cwm-glas, or Moelwyn, or Llyn-y-Gader on Cader Idris (fig. 2).

Two of the barest and clearest regions for the study

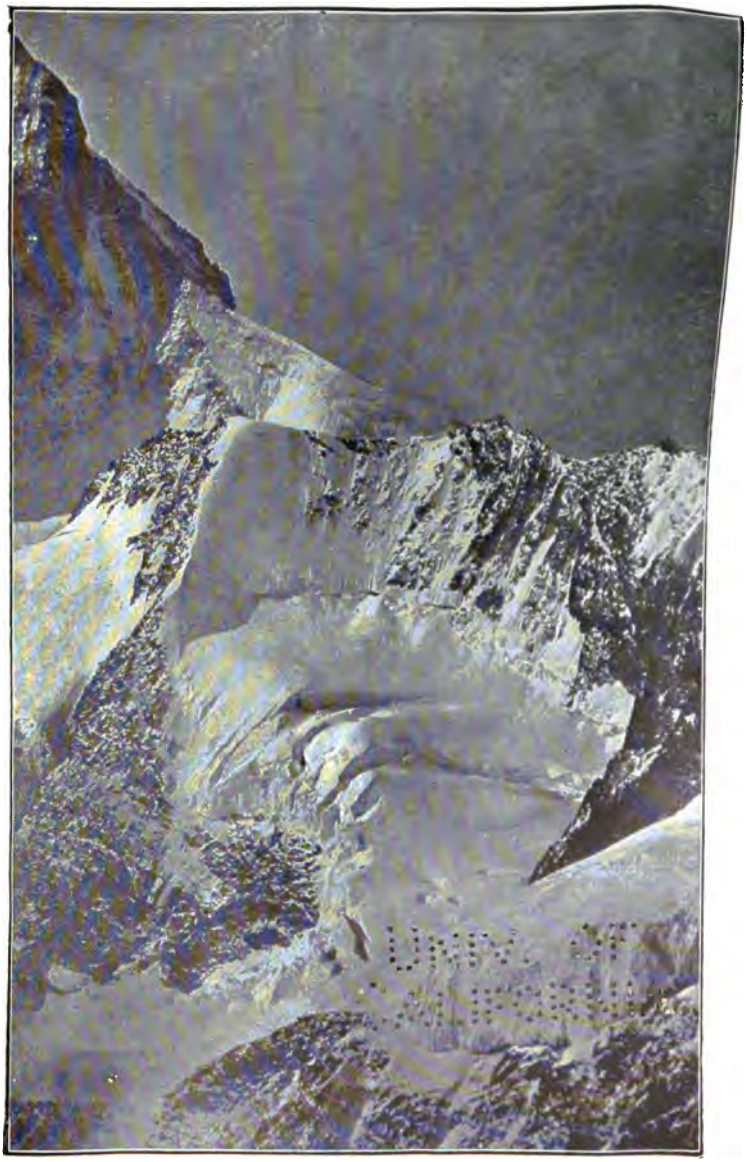


PLATE II.] SNOW-FILLED CIRQUE

AT THE BASE OF THE MATTERHORN, SWITZERLAND.

From a Photograph by the late MR. W. F. DONKIN, *by permission of* MESSRS. SPOONER & CO.

of perched blocks and *roches moutonnées* are the dark hollows of Loch Coruisk in Skye, and the more accessible region south of Killarney, along the road from Kenmare to Glengariff. Let us travel thither, and to Switzerland also, to continue our studies when we can. Meanwhile, any simple mountain-hollow will have taught us much in an afternoon.

And now, as we descend in the twilight, the clouds are already gathering on the crests behind us. We come down among the great loose blocks again, critically inquiring which of them have merely fallen from above and which have been stranded by ice-action. Some, like the grey flinty boulders so common on the hills around Llangollen, are obviously strangers, and must have been ice-borne from a considerable distance. When we at last strike the highway and tramp homeward through the dark, we can still hear the far sound of waters falling across the blackness of the rocks. And we know now that work is going on up yonder, and that next morning the sun will send his rays into the hollow, already shining upon new things and spying out the changes of the world.

FIG. 2.—CIRQUE AND LAKE, LOWER LOUGH BRAY, CO. WICKLOW.
(Photographed by the Author.)

CHAPTER III

DOWN THE VALLEY

THE course of any river is full of variety, as we follow it down from its source in the hills, through the long windings of the valley, across the open plains, and away to the distant sea. On every side there are things to interest us, and the river itself is the moving spirit of it all. Our great cities would not be where they are were it not for the rivers, which gave water to the early inhabitants before the days of deep wells and costly aqueducts. In many cases the town was established where ships, the light sailing-vessels of former days, could come up and land their merchandise direct upon the quays—just as great steamers still do below London Bridge, or at the Broomielaw in Glasgow, or along the Custom House quay in Dublin. In other cases the river divided hostile tribes, and the town grew up at some ford, where it was necessary to plant a fortress and to keep a constant watch. Whether we travel down the Thames, the Loire, the Danube, or the Rhine, we see how the flow of the water and the form of the river-channel have had their influence upon history. And then, besides all this, long before man came into the country, the river was working out an elaborate history of its own.

Many streams have simple beginnings, just as we saw among the barren highland rocks. The rain falls, and leaps in tiny cataracts down every crack and groove; on some shelf the water is stopped, and gathers as a little lake, or forms with the mosses a soft mountain-bog; from this a true streamlet rises, finding its way down among the grass-slopes and the fallen stones.

In some places, however, this water sinks in and disappears. Rain falls on sandstone or common limestone, where it becomes soaked up, and may sink to considerable depths. Such rocks, through which water can flow, are called *permeable rocks;* the water finds its way between the

mineral particles, or even, in the case of limestone, dissolves the material and works out little channels for itself. In our summer, the air is so warm and the days are so long that the rain which occasionally falls and sinks in becomes dried out again in the form of invisible vapour, and thus does not help to form an underground supply. But the winter rainfall, on the other hand, produces a quantity of water which flows slowly through the permeable rocks, and this is the supply that is often reached by the wells in old villages and farms. The ground becomes, in fact, water-logged, because the water cannot sink indefinitely towards the centre of the earth. It is soon stopped by some *impermeable* layer of rock, such as clay or granite, and continues to gather in the mass above. If the layers of rock have a slope in any particular direction, the water will flow

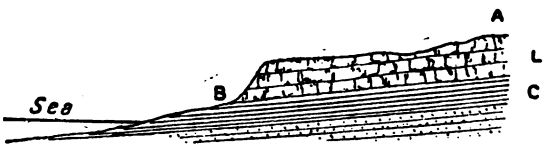


FIG. 3.—SECTION ILLUSTRATING THE ORIGIN OF SPRINGS.
A, inland heights; L, limestone; C, clay. Springs will emerge at B.

down this as long as there is some means of escape at the other end.

Imagine (fig. 3) a great layer of limestone resting on a layer of clay, and both tilted up so that the higher end forms the crest of a range of hills; and let the lower end come down to the sea-side, forming a limestone cliff, with the clay just showing on the shore beneath. Rain will fall heavily upon the heights, and will, in the colder months, accumulate as a great body of water in the limestone. The tilt of the rocks will cause this water to flow towards the sea, and it will produce a number of little streams gushing out over the clay surface on the shore. Here we have a *line of springs* formed, which will flow steadily so long as a good rainfall—especially a good winter rainfall—is kept up on the higher ground inland.

Springs arise where underground waters find a con-

venient outlet. When the gathering-ground of the water is high, we may sink a well upon some much lower portion of the permeable rock, and thus form an artificial spring. A "head" of water occurs in the distant mass at a higher level, which presses the water upwards in the outlet provided by the well, and forces it to flow out upon the surface.

Sometimes we may find a permeable rock lying between two impermeable masses, and the whole three layers may be bent into a basin-shaped form (fig. 4). Thus on all sides the permeable rock is exposed at the surface by this upward bending, and receives rain, which sinks into it. But the water runs down and accumulates in the centre between the two impermeable layers, thoroughly waterlogging the mass.

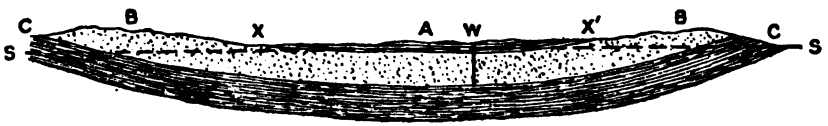


FIG. 4.—SECTION SHOWING PRINCIPLE OF ARTESIAN SPRINGS AND WELLS, AND ORIGIN OF BOURNES.

B, pervious stratum; A and C, impervious strata; S, sea-level. Bournes may arise at X and X', and an Artesian well may be made at W.

If we now bore down through the upper impermeable layer, anywhere near the centre of the basin, the water will rise freely; and, if the sides of the basin have been bent up high enough, it will flow out copiously as a fountain on the surface. Wells made under these conditions are called *Artesian wells*, from the fact that successful ones were constructed in the French province of Artois as early as 1126 A.D.

It will be clear that any permeable layer of rock will be drier near its upper surface, and that the water stored up in it will rise to a certain level in the mass, this level being nearer the surface at some times than at others. Any natural excavation or hollow which reaches down to the lowest of these variable levels will be occupied by a permanent spring. Many other hollows will be full of water in certain seasons only—usually after a succession of wet winters—and may

perhaps remain dry for several years together. Such temporary springs are called *Bournes* in the south of England, and are common on the surface of the soft white permeable limestone known as Chalk (fig. 4).

Water that has thus passed through a considerable mass of rock becomes filtered, and issues in most cases as a deliciously clear and cool spring. Near Albury, under the Surrey Downs, there is the famous Silent Pool, where the water comes out of the chalk along the surface of more clayey rocks, and is so transparent that one may stoop down and see the fishes apparently swimming in pure air. It is difficult to tell where the water below us actually begins. But this water has dissolved calcium carbonate (carbonate of lime) in its passage through the limestone, and is by no means chemically pure. Any material, however, that may have been held by the water in suspension, when it flowed on the surface of the Downs, has been completely filtered out during its underground wanderings.

Other underground waters gather compounds of iron in solution, and these compounds break up and oxidise on exposure to the oxygen of the air, forming hydrated iron oxide, which stains the water brown; this substance is itself insoluble, and is deposited as a film on twigs and stones over which the streamlet flows. In the neighbourhood of copper-mines, again, the rocks are sometimes wonderfully stained in vivid greens and blues, by the deposition of compounds of copper from a soluble condition in the springs.

Sometimes in a steep country-road, such as the lanes leading up over the sandstone of Leith Hill in Surrey, we may see, after rain, tiny examples of springs and streamlets, rising and bubbling through crevices in the surface. The ground below us has become temporarily waterlogged, and the little tricklings that come out along the cracks and easiest passages soon cut out channels for themselves in the roadway, just as streams do in a mountain-side.

Thus some rivers may arise in a series of well-marked springs, others from the outlets of mountain-lakes, and others direct from the melting foot of a great glacier. But the majority have their sources in a vast number of little tricklings, which wander through some soft bog-land on the upper levels of the hills. In our visit to the mountain-

hollow, we have already noticed such waters running through tiny channels just below the surface of the ground. They unite into little but well-defined rills, hundreds of which may go to form what we call a stream. And then somehow, with scarcely a distinct beginning, this stream leaps and murmurs on the hillside as a thing that can no longer be overlooked. Afar off we can see its waterfalls foaming; its course can easily be traced across the brown and purple of the moorland; and on either side of it the heather will shrink away, and grass and bog-moss will form soft green borders to the waterway. The old settlers planted huts beside it, and drove their cattle across the fords; it became a feature of the highlands, something distinct and interesting, a river at last worthy of a name.

Now, if we are going to study a river-valley, we may as well choose one that has plenty of variety, and that will show us the river in many moods. Let us come away into the eastern Alps, into the mountains of Tyrol and Karinthia, where the rocks and waters are always fighting it out one against the other. It is not at all a bad thing to look occasionally at the great showy diagrams of the world, and then to come back to our own islands with the certainty that Nature is at work there also, though the illustrations are on a smaller scale.

It is a wonderful landscape that greets us as we rise in the early morning, after our long railway-journey across the heart of Europe. Our Tyrolese village, with its square white houses, roofed with pine-chips, and its church-towers terminating in quaint vermilion bulbs, lies still and dark between the forests of the valley-head. A band of cloud still wanders slowly between us and the upper pastures, where two or three brown châlets are catching the first shafts of sunrise. Along the high-road, the road to Karinthia and the east, a white-sleeved and blue-aproned peasant is driving some fifty or sixty goats with tinkling bells. The clock on the old market-house strikes four, and we look up and see that the clouds have already almost left the woodland. All round us the peaks are rising in a pale blue air of morning—not the great snow-masses and glacier-basins of Switzerland, but mountains stranger and more fascinating than these, crest and ridge and pinnacle of clear grey limestone; and to-day each ledge is marked by freshly fallen snow, which picks out the outlines

of the crags, and which nowhere veils them. The level sunlight makes all the eastern side of these pinnacles a warm and golden brown; we can see the deep clefts and knife-cuts, as it were, between them, and the steep shoots of fallen stones in every groove beneath the crags. If a block falls now, we may hear it in the stillness, leaping in great bounds down the grey talus, and starting a rattle of smaller ones along its track. Those peaks and barren walls not only mark a region too high and cold for trees; they also extend wherever denudation is still active, the limestone, with its huge vertical joints, sending down block after block, and offering no resting-place for the fir-woods. Wherever the layers of the rock are bent into long sloping curves, with no sheer crag above them, there the trees have climbed up in safety, and look down the precipices upon the denser woods below.

Wherever a recent fall of rock has occurred, the scar upon the mountain is pale yellow or orange-brown, the colour gradually darkening as weathering goes on, until the surface again becomes uniform and grey. We have only to glance round to see how frequent such falls are, and how the taluses, concerning which we speculated among our British mountains, are here growing almost before our eyes. It is fairly easy to distinguish the recently fallen from the older blocks upon them; and away there in one place an unusual down-rush has crashed into the lower forest, rooting up the spruce-firs and the larch-trees; and their dead stems, sloped over towards the valley, are seen in forlorn clumps here and there, surrounded by angular blocks of limestone. The grass has gone, the whole loose slope of the forest has been channeled out, and the track of the great stone-slide resembles the hollow of a stream.

Among these broken forest-slopes, between the clumps of rhododendron, and whortleberry, and vigorous heather spreading towards the open air, we find damp little patches of bog-moss and rich grasses, where springs, fed by dew and snow, gather and begin to bubble forth. All these go to feed the rapid torrent down below, which is bridged by the high-road in the village.

If we were to come just as the winter snows are melting, each of the humble tributaries of this torrent would itself be seen in all its glory. At present they are lost among their great stone-banks, among the conical taluses in which each

one ends towards the valley. But the stones in these cones are often rounded; the water has evidently strength enough at times to roll one against the other; and the wonder is that the central valley is not choked up by the activity of these irregular side-streams.

On the eastern side of the Arlberg Pass, leading down to Innsbruck, one may see magnificent cones of this kind, at the base of the most insignificant grooves in the upper rocks. Year after year the streamlets rise in flood, and shoot out the *débris* which is daily collecting in the cleft. The huge cone, on which vegetation tries here and there to cling, receives a new coating, and sheds some blocks, new or old, into the valley. Like a cloud-banner gathering on a mountain, it is constantly being added to at one end, and carried away piecemeal at the other. Frost, and the insidious rootlets of plants, and mechanical grinding together in the waters, finally break up the lower blocks; and the main stream has power at these high levels to carry off the detritus, and to allow of further accumulation at the upper end.

This "creep" of the whole hillside downwards, leaving the crags as much exposed as ever to the attacks of denudation, is a feature of any steeply sloping country. Our old buildings frequently give evidence of it; thus the Abbey of Valle Crucis, near Llangollen, built in 1200 A.D., is buried on its north side some seven feet by the creep and accumulation of the fields, which now stretch evenly from it towards the valley-side, with walls and houses built upon them. The cathedral at Lismore, again, on a steep slope above the Blackwater, is similarly banked about with earth, which seems to have crept down upon it from the south and to have flowed gradually round it. Of course such evidence of forward movement of the soil can be best gathered where the building which has formed the obstacle has been allowed a long period of disuse and disregard.

It is obvious that the river in our Tyrol village must still be powerful enough to cut out its course and to deepen the whole valley in which it runs. Records of floods and of disastrous denuding action are abundant in the history of the village. Houses have been cut in two, road-embankments have been swept away, whole fields have been swallowed up in stones or carried down into some neighbouring hollow; and this sort of thing may happen every six or seven years,

giving the inhabitants a continual struggle with the stream. In places the pebbly area on either side has been abandoned to a rough growth of young willows, through which a few shifting paths lead to the swift green river, the actual bank of which is always varying its position. Where such variations become dangerous, embankments are built out, in stone and timber, and attempts are made to "correct" the river and to give it a fair straight course. All the bridges are made of wood, and can be repaired by local carpenters; a stone bridge would be so much waste of time and money. Even the side-streams, which may be dried up for half the year, have their floors artificially paved, and are conducted with care in stone-lined channels across the slopes. Everywhere the water, armed with the stones supplied to it from the crags, is recognised as an enemy, as a battering, cutting, and swirling agent of destruction.

To pass down one of these valleys of the Eastern Alps after a season of storm and flood is indeed a lesson in denudation. Among the undermined and shattered houses, every active peasant is turned out to cope with the pebbly wastes, which have encroached upon the highways and the fields. The women, with baskets on their backs, are working knee-deep in the stream, bringing loads of stone for new embankments, until the water is "corrected" once again. Here and there, in the narrower gorges, we may find the road carried away for several yards, and timbers laid down provisionally across the gap, until a new foundation can be built up firmly from below.

The great ravine of the Valle del Ferro in the Venetian Alps, through which a railway now runs from Karinthia to Italy, shows striking examples of the excavating action of a torrent. Here working in behind some projecting spur, and widening a vertical joint until the little promontory becomes an islet; here battering at the heavy masonry that supports the road, until foreboding cracks open in it upwards from the base; here taking advantage of some fold or grouping of the layers of the limestone rock, and eating out caves at the foot of the enormous precipices—everywhere the river can be seen in its full health and strength, fashioning its own gorge, rolling down the pebbles along its bed, and cutting like a saw across the very ridges of the Alps.

As we leave our village in the valley-head, we soon come

to a region where no further cultivation is possible, and where the châlets have been posted on green ledges high up above the stream, or have altogether vanished, owing to the steepness of the mountain-sides. We enter, in fact, one of the **gorges** or **cañons**[1] that are so typical of the excavating region of a stream.

The torrent, if left to itself, would naturally cut a deep vertical cleft in the rocks presented to it. But to do so it must work rapidly; for other agents are all the time smoothing back the walls of the groove, sending down taluses into the direct course of the water, and tending to produce an ordinary valley with gently sloping sides. Some of these cañons, as the Americans call them, are so surprisingly sheer-sided that older observers used to consider them as great rents in the earth into which the rivers had found their way. Everything goes to show, however, that they are merely repetitions on a large scale of the little gullies that occur in any mountain-streamlet. The water has laid hold of some line of weakness in the rocks, and has worn out its channel energetically along it. All rock-masses are traversed by thin cracks, frequently running parallel to one another over great distances, and known as *joints*. In some cases these joints are due to the shrinking of the rock after it has been formed, as occurs in many melted rocks on cooling; in most cases some internal movement in the earth has twisted the rocks, and has produced a great series of parallel and intersecting cracks throughout them. These joints, as we must have noticed again and again, enable the rocks to be broken down by frost or by quarrymen in huge masses at a time; they also serve as ready assistants to the river. One set of them is likely to be practically vertical, and the water may happen to run approximately in this direction. Some one joint is laid hold of, and is rapidly widened by the flow. Its walls, owing to the parallel joints in the mass, become worn back vertically, the rock flaking off in slabs on either side; and the gorge, when once started, may weather back and widen at the top, but will deepen and deepen, until the torrent flows in a mere knife-cut of a valley at the bottom, its sides towering almost sheer in cliff and terrace to a height of half-a-mile or more. In the famous ravine of the Via Mala, on the Splügen Pass in Switzerland, the lowest cut is

[1] Pronounced "can-yons."

in places oblique, and is so narrow that, on looking into it, the overhanging side conceals the stream from view. In all cañons it is interesting to see whether the directions of jointing, or the relations of hard and soft rocks lying against one another, have influenced the general direction of the water-flow, and consequently of the resulting gorge.

In the ravine we now enter, nothing strikes us so much as the ease with which it might be choked for a time by any ordinary rock-fall from its sides. Such falls must speedily be obliterated by the torrent, or the period of excavation would soon be over. As we go down the road, which is in one place cut in the wall of the precipice, in another built out into the stream, we see above us steep side-gullies opening into cirques among the higher peaks. Stones stand in the mouths of some of these, ready to be driven over in some day of desperate storm. A few such blocks might serve to close the channel altogether. But the force of the river is so great that it bursts such dams again unfailingly; a few masses are left, like islets towering from the foam, and the others, shattered and broken down, are added to the pebbles which rattle against and undermine the cliffs. The river again asserts itself and continues to deepen the ravine.

Such a gorge, with occasional glimpses into the recesses of the mountains far above, may continue for seven or eight miles. A steep cone of detritus clings here and there beneath some channel of falling water on the sides; but for the most part the walls are grim and sheer. A sharp eye may sometimes detect old stream-levels on the higher portions of the cliffs, where the torrent formerly could undercut the wall or has drilled out a long-fronted and shallow cave; but these levels have been long ago forsaken, and the cañon is still in process of formation—it has not yet reached its greatest splendour.

Its mouth opens on an expansion of the valley, with a green flat floor, eagerly seized on by the agricultural peasantry. The rocks here may be different in character from those hitherto traversed, and the torrent, sweeping from side to side, has been able to widen back the valley. Or side-streams may have indented the walls and brought down more material than could here be swept away. Clearly at some time the valley has been choked, and the work of

the main stream has then been confined to spreading out the detritus evenly. If, for instance, a talus-fan, the broad end of some huge cone, has encroached upon it, the river has worked away at the base of it, and has laid out the material in level stretches across the floor. The talus and its fellows on either side have continued to slip forward, and the stream has risen upon the pebble-beds which it cannot sweep away. Dammed back occasionally by a slip of greater magnitude, it has overflowed its bounds and converted the expansion of the valley into a lake. The head of water thus produced has at last overcome the barrier, and the level pebble-banks, gently deposited during the lake-period, have become drained fairly dry, and have been finally covered with vegetation. The river is now seen wandering through them, as it did through the meadows of its gathering-ground; and, as it cuts its way down again in a narrower channel, it becomes turned to one side or the other by any large block that bars its way. Its course is thus winding and uncertain, and it sometimes forms long loops and doublings, only to cut through finally by a more direct route, leaving its former curved bed desolate and dry.

Such a grassy level, with the stream winding across it, is styled an **alluvial flat**, and the material laid out by the river is known as the **alluvium**. The stream is frequently cutting away its bank on one side and depositing pebbles, the new alluvium, on the other, where some promontory or sharp bend checks the flow. Hence the alluvium is always undergoing redistribution, and is liable to be flooded over at any time and restored to a fairly uniform level.

Such basins of alluvium, which are frequently the site of ancient and temporary lakes, are common along Alpine rivers. As we cross this one, we see the valley again contracting; the road drops more steeply, and enters a wilder country in a series of bold windings; and soon we are in a second gorge—we have left the area of arrested flow and of deposition for another one of rapid excavation.

In this way, limited by a number of local accidents, the alluvial flats, with villages clustered on them, and grim defiles, echoing only the roar of waterfalls, succeed one another in this active portion of the river. In time we shall reach an area, some 2000 feet or so below the sources of the stream, where the flow is no longer sufficient to do

much in the way of excavation, and where ordinary atmospheric agents, rain and frost and wind, have had things mostly their own way. The valley becomes a more ordinary one; that is, it has grown wider far more rapidly than it has been deepened.

Here, then, the talus-cone will appear in its best development, stretching from the pebble-strewn floor of the valley backwards at a gentle angle towards the crags. If we look closely, the prominent features of the lower slopes will be seen to arise from the arrangement, and even from the overlapping, of these great detrital fans. In places they have become fairly consolidated; trees have grown upon them; and the side-streams to which they owe their origin never in these days flood across the whole. By successive downpourings of boulders, the water has slowly raised itself, running upon the central line of the conical slope; and then, in ordinary weather, it cuts little channels in the yielding material and tends to undo its work of deposition. But every now and then it rises fiercely and spreads new pebbles broadcast; the old channels are obliterated, and, when the storm is over, a real addition has been made to the cone, a real step forward has been taken towards the ultimate destruction of the higher crags.

The result of this uplifting of every torrent upon its own fan of detritus is that the villages in our valley are so situated that we go uphill into them from either side. They had to plant themselves where they could get at the water, and there is consequently a wooden bridge in almost all of them, at about the highest point of the road across the cone. This is contrary to one's ideas about well-conducted streams, which usually run in valleys of their own, instead of on these broad and convex slopes.

To secure the houses from being attacked, the stream has to be rigidly "corrected"; but there are acres on either side of it which have a very fluctuating value. And the lowest part of the fan, though covered with a straggling fir-wood, is traversed by numerous branches of the stream, like the mouths of the Nile delta, and is thus practically useless for cultivation. Below stretches the waste of alluvial stone-banks and dwarf willows, with the main stream rushing aggressively in the midst of it, along its variable curves.

This type of valley-side is continually presenting new

problems to the peasant. The vast taluses, banked up one against the other, have no firm connexion with the rocky wall behind. The swirling action of the river at their base, or a few hours of rain, lubricating the pebbles and soaking far down within the mass, may upset their equilibrium and cause a widespread movement. Such **landslides** are so frequent that men are enrolled in every commune, whose duty it is to turn out and to help to reconstruct the roads.

I was cycling with a friend one evening across the broad talus-heaps to the east of Imst, not far from Innsbruck. It was a wild summer, with thunderstorms every night amid deluges of August rain; and one of these sudden downpours had just reached us. We were pushing on in the dusk through the rough and ragged woodland, where few of the trees enjoy sufficient quiet to grow into a handsome middle-age. All at once we saw that the road had given way before us; the stones were moistened with the rain, the limestone dust between them being converted into mud; and the hill-side was here in motion like an oozy river across our track. It was a striking sight, this steady flow of stones, into which we could have dipped our hands; but our position, and that of our machines, were too insecure to allow us to stay long upon the brink. We retraced our route for some miles, noting at other points how suspicious yellow mud-flows were beginning to creep out across the roadway. Next morning we found that the material had come to rest, after cutting a groove in the more coherent portion of the slope and flowing down into the main valley of the Inn.

To dwellers in these valleys such accidents are part of ordinary life; and the extensive areas of gently shelving ground that remain untouched by cultivation show how these lower slopes are continually liable to change. A map of such a country on a large scale, say 1 : 25,000, or two and a half inches to a mile, would be out of date after any stormy season.

Landslides of fair magnitude may actually dam up the main stream, and may thus cause a rapid flooding of the higher portion of the valley. Such slides are common in the gorge of Lienz, the material coming down from the side-valleys into the narrow channel of the Drau; and these heaps of detritus have to be cut through artificially, to check the formation of a lake which ultimately would overflow and burst out down the gorge. In former days, this excess of

supply over the means provided by Nature for carrying it away has choked many ravines, and has even formed permanent and narrow lakes within them. More often the evidence points to the lake having burst through the barrier; and the torrent has since reasserted itself, and has carved its channel easily down to its former level through the thickly accumulated alluvium of the lake.

But remarkable changes may occur in the geography of so unstable a district, and that in a few hours, especially in areas where man is not on the alert. Let us imagine a pass in the mountains, where two rivers rise, one falling down an eastern, and the other down a western slope; and let a side-stream enter the eastern river, close to the summit of the pass. A landslide from a neighbouring mountain may occur, and may cross the junction of the tributary and the main stream; it may thus divert the former into the western river, providing a slope for it across the pass, and so profoundly altering the system of natural drainage. Such an event might easily have happened at Toblach, in central Tyrol. The river Rienz has already been invaded by taluses, which have formed the little Lake of Toblach; and a great slide from the Sarlkofl might even now turn its waters eastward, and thus drain the Höhlenstein valley into the Black Sea instead of into the Adriatic.

So we may fully recognise, as we before hinted, that maps of uncultivated countries, if we only make them large enough to show the details, are at least as often in need of rectification as the plans of rapidly growing towns. We said rightly that Nature was at work all round us.

In these higher valleys, the changes wrought by ordinary landslides may be altogether surpassed by true **landslips**, which are often catastrophic in their scale. Records of terrific rock-falls are common in the history of Alpine villages; as usual, the more magnificently developed the mountain-range, the more it is exposed to violent action, the more rapid are the phases of its decay. The rocks of a great chain, as we shall see in another chapter, are intensely folded one upon another, and hard layers may lie inclined upon softer ones at steep angles among the mountain-peaks. Enormous masses, once connected, become cut into fantastic forms by denudation, and finally may be undermined and may be rendered utterly unstable. From one cause or another, whole mountain-crests

may become loosened and detached; thus in one case an earthquake released the mass, in another the balance was disturbed by simple quarrying-operations at its base. Landslides and landslips of course graduate into one another; but the typical landslip is a thing that cannot easily be foreseen, and that may result from centuries of stress among the folded masses of a mountain.

It is difficult for us to conceive in the British Isles the far-reaching effects of one of these huge rock-falls. As we said when we sat among the *débris* in our mountain-hollow, our own hills have got past the stage of violent catastrophes. The great landslip near Axmouth, in Devonshire, which occurred in 1839, gives one some idea, however, of the changes that may be produced in a few hours. Sir Charles Lyell, in the later editions of his "Principles of Geology," has made us familiar with its details. At this part of our coast massive beds of chalk and sandstone rest upon clays, which slope outwards towards the sea. The permeable rocks allow water to soak down until it reaches the clay, where it lubricates, as it were, the natural inclined plane provided. On December 24, 1839, about a mile of the coast slipped seaward, producing great rents and fissures in the mass, and forcing up the broken material on the shore in front of it to form a ridge some forty feet in height. (See also *Mem. Geol. Survey*, "Cretaceous Rocks of Britain," vol. i. (1900), p. 193.)

The east coast of County Antrim, from the occurrence of a precisely similar series of beds, is continually subject to small landslips, and at Garron Tower a mass of chalk, capped by basalt, nearly two miles in length, has sunk 100 feet and more from the main plateau, owing to the yielding of its supports.

In the Alps we have unfortunately too many records of landslips in the upland valleys. With very few exceptions, they have occurred in the areas of stratified rocks, that is, rocks disposed in layers one upon the other.[1]

One of the most recent and most carefully studied instances is that of Elm, among the Alps of Glarus, which was reported on by Professor Heim. On September 11,

[1] See Neumayr, "Ueber Bergstürze," *Zeitschr. der deutsch. u. œsterreich. Alpenvereins*, Bd. xx (1889); A. Irving, "'Bergstürze' or 'Landslips,'" *Geol. Mag.*, 1883, p. 160.

1881, a rock-slip descended from the Tschingelberg above the village, three falls occurring in twenty-one minutes. The *débris* came down like a waterfall, the enormous blocks leaping from terrace to terrace of the mountain, and finally rushing on like a flood over nearly level ground for about a mile. This river of stones even scaled a hill to which a number of the villagers had fled for safety, and it travelled in the valley-floor at the rate of thirty miles an hour.

In 1806, a mile of the face of the Rossberg, a mountain at the south end of the Lake of Zug, fell into the valley between that lake and the Lake of Lowerz; 457 persons perished, and the huge blocks of conglomerate were heaped across the pastures and the villages. At the present time the area is traversed by the St. Gotthard railway, and on all sides the sharply angled masses, as large as houses, can be seen scattered across the slopes, in a matrix of gravel and fine sand. The old rocky bosses in the valley have been swallowed up by the great flow of boulders, which have climbed the hillocks and lie like perched blocks upon their summits. The bare crag of the Rossberg rises two miles away above this extraordinary and impressive landscape.

A similar scene of abrupt destruction is crossed by the high-road from Italy, as it ascends to Cortina in Southern Tyrol. The last great slip took place here in 1814; and the road is at any time liable to be invaded by a further creep downwards of the *débris*. Both here and beneath the Rossberg, respectable little fir-trees have already planted themselves upon the boulders, and serve to emphasise the enormous size of the fallen masses.

Professor Heim has also pointed out how the valley of the Vorder Rhein, from Ilanz to Reichenau, has been invaded in very early times by a landslip from the neighbourhood of Flims. The detritus has formed hills 1800 feet high above the valley-floor, and the whole mass of this prehistoric fall is calculated as 15 cubic kilometres,[1] or 1500 times as great as that of Elm. In fact, a range equal in size to the Malvern Hills seems to have been abruptly

[1] A. Heim, "Der alte Bergsturz von Flims," *Jahrb. des Schweizer Alpenklub*, Bd. xviii (1883), p. 300; and Heim, "Geologie der Hochalpen zwischen Reuss u. Rhein," *Beiträge zur geol. Karte der Schweiz*, Lieferung xxv (1891), p. 431, and pl. vii, fig. 6.

planted in the Rhine valley, as a mere incident of the long series of attacks which have been going on for ages, and which will ultimately destroy the Alps.

It may be worth while to try and find some measure for the masses which are thus transferred in a few minutes from the crest of a mountain to its foot. Any visitor to Dublin is familiar with the bold promontory of Howth, which rises like an island on the north side of the bay. It is a picturesque feature, rising 560 feet above the sea, and is about two miles across in all directions. Its form makes it possible to calculate its mass above the sea-level with fair approximation. Now the Elm landslip brought down 10,000,000 cubic metres of rock, and ninety such falls would destroy the whole of Howth. Sixty landslips like the Rossberg would similarly remove it; while the two great falls from the Diablerets in central Switzerland in the last century were together equal to $\frac{1}{18}$th of Howth. The prehistoric landslip of Flims, however, according to the figures of Professor Heim, would have removed seventeen Howths at a single blow. The mass of material brought down would, in fact, have built a causeway fifty-six miles long, half-a-mile wide, and 660 feet in height.

The Isle of Wight, with its area of 155 square miles, may be expected to form a feature of our south coast from this time on into far-distant epochs. But, were its rocks elevated into the perilous positions occupied by beds of the same age in the Alps, their existence would at once become endangered. The matter is brought home to us somewhat startlingly when we realise that the catastrophe of Flims would have carried away half the island.

We have already seen how our typical Tyrolese valley is liable to be converted locally into a lake by landslides from the mountain-walls. A considerable and abrupt landslip may similarly dam up the river, and may even provide a permanent barrier. A fine example of this kind occurred in India, in September 1893, in the neighbourhood of Srinagar.[1] The rock-falls from a mountain above the village of Gohna continued for three days, accompanied by clouds of white limestone dust, which spread for miles. Blocks, as at Elm, were projected for distances of a mile, and broke down trees across the valley. A wide dam of detritus, weighing, on Mr.

[1] T. H. Holland, "Report on the Gohna Landslip, Garhwal," *Records Geol. Surv. of India*, vol. xxvii, p. 55.

Holland's estimate, 800,000,000 tons, finally occupied the hollow, and converted the upper reaches into a lake three miles long and a mile and a quarter wide.

Mr. Holland's prediction as to the date when this lake would overflow was verified almost to a day in August 1894. A gorge was speedily cut through the dam, a great rush of water occurring in the first few hours. The geological effects of this flood, moving at twenty-four miles an hour and rising 150 feet in some parts of the valley, gave a valuable lesson in the distribution of stones and boulders.[1]

Our contemplation of the huge unstable taluses, and of the old rock-scars above them, must now for the time come to an end; we must move farther down into another region of our valley. Here the floor is flat, and is used for smiling meadows; but the walls on either hand come down vertically, in striking contrast, and there seems no relation between the sides and the bottom of the valley.

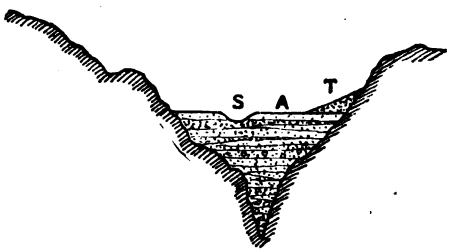


FIG. 5.—SECTION OF GORGE CHOKED WITH ALLUVIUM.

A, alluvium; S, the subsequent groove formed by the stream; T, a talus or detrital cone, which has grown out over the alluvium.

We stand at the foot of one of these great cliffs, and look across at the opposite one a mile or more away. We have here something like the gorges of the higher regions, only on a somewhat bolder scale; but the area from cliff to cliff has been filled in with alluvial pebbles (fig. 5). It is a portion of the valley where deposition has, for a long time, been in excess of excavation; too much detritus has been cast into the stream.

It may be that landslides and stormy seasons aided in the choking of the valley; and the stream may now be cutting its way down again, swiftly and dangerously, between cliffs of loose alluvium. The valley of Aosta on the south side of the Alps shows us banks of pebbles now cut through

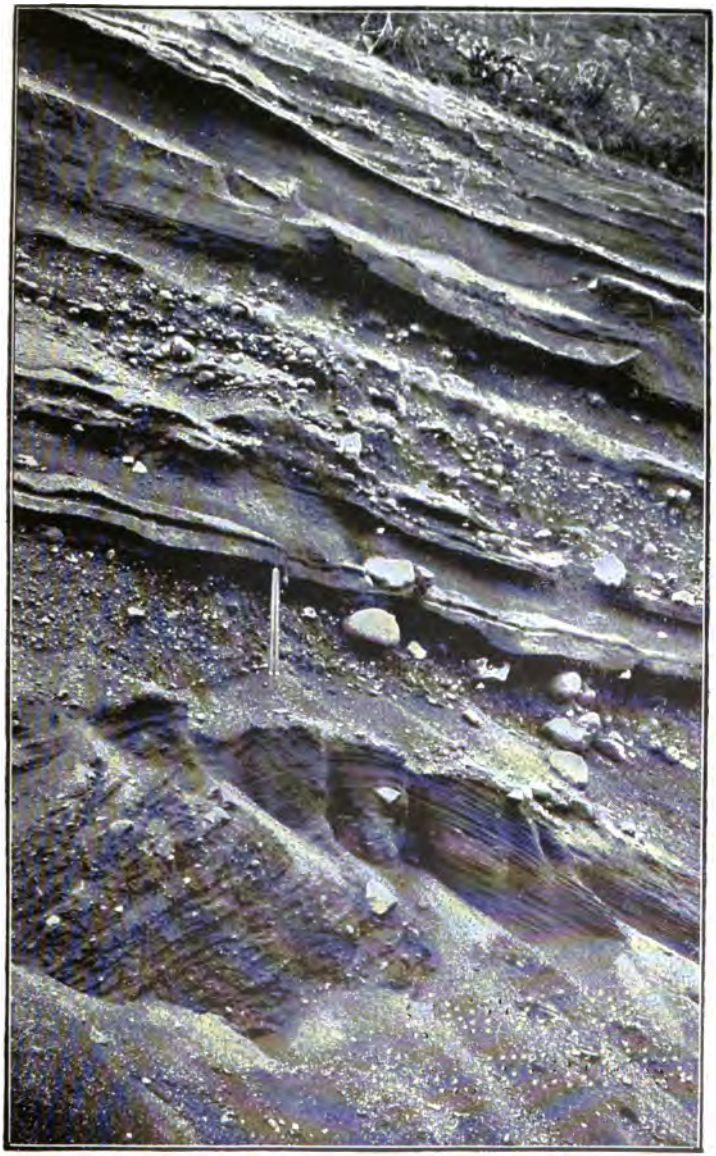
[1] *Nature*, vol. l. p. 596, and private communication.

in this way, and the railway-engineers experienced curious difficulties in making their artificial cuttings. Some of these had to be roofed over and converted into tunnels, to prevent the constant slipping in of the sides. In the case of rapid streams, the banks are always changing, and short work will be made of the alluvial flat if artificial checks are not resorted to.

Sections in the alluvial infilling of our valley will give us an insight into the work of the river as an accumulator; and it will be well to find our way down one of the steep zig-zag paths to a little bridge, from which we can view both banks. The pebbles are not thrown down without method or arrangement, as they might be in the products of a landslide which has come to rest. On the contrary, a distinct grouping in beds or layers is visible (Plate III). Here a coarse mass of boulders lies heaped together, the rounded blocks sticking out conspicuously on the steep bank above us, like skulls in a giants' graveyard. But below them the pebbles lie with their longer diameters generally horizontal, as they would if one took a heap of them and smoothed it out on a flat table with the hand; the water in this case has acted as the hand, and has, in swaying them this way and that, finally formed a layer of them, which we technically term a **stratum**. The plural of this word is *strata*, and when we say a rock is *stratified*, we mean that natural agents have deposited its constituents in a series of strata one upon the other.

Beneath the stratum of pebbles comes one of sand, with a few small stones scattered through it. When this was formed, a quantity of finer material, perhaps a muddy and sandy flow from some side-valley, was being brought into the higher reaches of the stream. Or the stream itself became checked in its flow by alterations in its course or in the form of the valley-floor above, and could no longer carry along the larger stones. So it merely brought away the finer sand, with a few little pebbles, and for a time made beds out of these, as if there were no coarse materials up the valley. We shall see later, in observations at the river-mouth, how far this process of natural sifting may be carried.

If we examine the coarser strata in this section of the alluvium, we shall find the sand there also; but it is distributed between and over the surfaces of the stones, which are far more conspicuous. Under the bridge some one has



STRATIFIED SANDS AND GRAVELS,

SHOWING FINE AND COARSE MATERIALS, ANTRIM.

PLATE III.] [*Photographed by* Mr. R. WELCH.

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confidingly left one of the shallow wooden pails which are used for carrying water or milk, or for washing clothes, throughout this mountain district. If we borrow it, and throw some of the material from a coarse-grained stratum into it, we can imitate the final separating action of the stream. Let us fill up the pail with water and shake it briskly from side to side. If we pour the contents out quickly, the rush of water will carry with it pebbles and sand and mud alike, and we reproduce the action of the river when it formed the original stratum. But if we deal more gently, we find the top layers of the water becoming thick with the mud and sand, among which, if the sun is shining, we can see a number of tiny flakes of mica gleaming; and now we can pour off this finer material and leave the coarser and more unwieldy stones behind in the bottom of the pail. The particles of sand and mud and fine mica have probably quite as high a specific gravity as the stones that remain behind; but they offer so large a surface in proportion to their mass that they are easily washed about in the water and become poured off with it.

We have now imitated the action of the river when its current is more gentle, and when it begins to sift apart the alluvial materials for redistribution in the lower part of its course. We may even go further, and by careful washing, and by allowing the disturbed material to stand for a short time, we may find that the sand will settle, while the finest mud can be poured off. Then we can, as a second stage, wash away the sand, leaving only the coarser pebbles; and thus we may, like the river in some places, produce a triple separation.

The layer-structure, which we call the *stratification*, is not very regular in these rough materials, and no one stratum extends for any long distance in the section shown us in the bank. The beds of finer sand lie on one another, sloping in various directions, a certain number being deposited by a current swirling one way, and then others following under the influence of a different movement of the stream. Such a structure, where the beds do not all slope one way, is known as **current-bedding**. This irregular stratification is further disturbed by the pressure of coarse boulders, which become rolled down in exceptional seasons; and the group of blocks sticking out above us proves how very variable is the action of a mountain-stream.

When a great bank of such detritus has been exposed for a long time to rain and weathering, gullies are cut in it by the storm-rills from above, and these vertical grooves become rapidly deepened. But the larger blocks serve to protect the portions immediately below them from denuding action, and conical pillars result, carved out by rain, some exceptionally large stone forming a cap at the summit of each. These tall cones can be seen on any hillside where banks of old detritus have been subsequently excavated into cliffs; Glencullen, near Dublin, contains fair examples of these *earth-pyramids*, and the soil at the bottom of any hedge, when examined after a shower, will show the same feature pleasantly in miniature.

The more we remain in the bottom of the present stream-cut, beneath these walls of loose pebbly alluvium, which perhaps rise 100 feet above us, the more we shall believe in the carrying power of the torrent. Its action is so violent that even the hardest rocks are converted into smooth round pebbles by friction one against another; and Professor Bonney[1] has told us that 3000 feet of descent in the upper reaches of an Alpine stream is sufficient to round pebbles of ordinary hard rocks, such as granite. As we noted upon the mountain-slope in our own islands, the smaller materials become more slowly rounded than the coarser, owing to their being buoyed up and kept apart by the flowing water. A stream travelling at four miles an hour at the bottom of its bed can move forward pebbles nine inches in diameter, and two-inch pebbles can be moved by a flow of only two miles an hour at the bottom.

The steep slopes of the stream-beds in the upper region, the region of excavation, greatly assist the rapid denudation of the valley-head. A Bulgarian student, M. Baëff of Shipka,[2] has recently given us some interesting results of a year's observation of the Arve, one of the most striking torrents of the Alps. He finds that the solid material brought down by this river in suspension is greatly increased by only a slight increase in the volume of the water, while the matter carried invisibly in solution is much less variable in amount. The level of the river is highest in summer, which is likely to be true of any stream resulting from the

[1] "The Rounding of Pebbles by Alpine Rivers," *Geol. Mag.*, 1888, p. 60.
[2] "Les Eaux de l'Arve;" Geneva, 1891.

melting of snow and glacier-ice; and any increase in volume of a stream upon a steep slope means a great increase in its velocity and its power of transporting pebbles. The total quantity of material removed, both in suspension and solution, from the mountains of Savoy by the Arve during the year 1890 was found to be 965,457 English tons, a very considerable figure when we remember that this action is continuous. This is, of course, a true torrent, the Arve of Shelley—

> "Where power in likeness of the Arve comes down,
> From the ice-gulfs that gird his secret throne,
> Bursting through these dark mountains like the flame
> Of lightning through the tempest."

But the denuding work of rivers may be appreciated when we remember that an almost equal amount of material is brought down annually by the Thames. In this case,

FIG. 6.—SECTION SHOWING A SLOPE OF 1 IN 17.

however, the great bulk is carried in solution from the extensive tracts of limestone over which the river flows.

The actual fall of the River Arve in the first twenty-eight kilometres of its course, through the Valley of Chamonix from the ridges of Mont Blanc, is 1700 metres, or 1 in 17[1] (fig. 6), the steepest slope that an ordinary railway train can climb being about 1 in 38. If we take an example from the mountain-streams in our own islands, say the River Liffey as it descends from the moorland down into the county of Kildare, we find that it has a fall in the same distance of only 336 metres, or 1 in 83. The Rhine, again, as an example of a long river, with its course of 760 miles, falls on an average 10 feet per mile; but in the mountainous part of its course, from the glaciers on the Bernardino,

[1] That is, if we measure off 17 metres, or kilometres, or feet, or inches, along the river's course upon a map, in that distance the floor of the valley has approached 1 metre, or kilometre, or foot, or inch — according to the unit selected—towards the level of the sea.

through the alluvial fields of Splügen, and down the ravine of the Via Mala, it falls 200 feet a mile, or 1 in 26. From Bâle to its mouth, on the other hand, it descends only about 1.6 feet per mile, or 1 in 3333.

But no mere comparisons can give us the true effect of our Alpine torrent, as it comes down in Tyrol uncontaminated by glacier-mud, clear and green and swirling, rejoicing like a giant to run its course. Like most good things of the world, it compels us to go forth and visit it, if we would grasp its meaning thoroughly. It varies in habit from point to point, now cutting its groove, now laying down its burden and spreading itself out in lazy shallows, as we reach the gentler portion of the valley.

Here, for instance, is a long stretch of alluvium, where the river is now powerless to do more than redistribute the detritus during occasional floods. The sheer sides of the valley show that in former ages cutting action was predominant; but the gorge is now choked, the gathering-ground of the torrent has been lowered too far by denudation, and the period of deposition has finally set in. The story of all streams is alike—excavation at one end and deposition at the other; and the area of deposition extends slowly back up the valley as time goes on.

The Rhine, between Chur and the Lake of Constanz in eastern Switzerland, shows the alluvial stage very strikingly. Old stone causeways have been discovered some 15 feet below the present surface of the valley-floor; and the cliffs at Hohenems and elsewhere drop sheer into the alluvium, showing the former gorge-like character of the valley. The river and its tributaries have brought down so much material that the whole course of the water has been changed by the detrital banks. In prehistoric times the Rhine flowed past the site of Sargans, and away through a narrow valley which it had cut for itself to the north-west. The Lakes of Walen and Zürich occupy part of this old course of the Rhine; but the streams flowing from Sargans into the gloomy hollow of the Lake of Walen are now very trifling in their volume. By slight shiftings of its alluvium, the Rhine has banked itself out of the ravine of the Lake of Walen, and has crossed northward into another valley leading down into the Lake of Constanz. The relations of these two valleys can be seen in any good atlas; and the levels around Sargans are such that it would

require no great feat of engineering, the cutting of a barrier only fifteen feet in height, to turn the river again into the deserted gorge of Walen.[1]

Little hills, which have escaped complete burial, stand out above the general flatness of the Rhine-alluvium; but on the whole the floor of the present valley is in singular contrast to its sides. The Ill comes in at Feldkirch, bringing down pebbles from the Arlberg Pass; and it shoots out from a fierce little gorge into a great alluvial level four miles wide. Fifteen miles north of this the Lake of Constanz opens, and arms of detritus are being thrust out into it, and threaten in time to cut off the port of Rorschach from Lindau.

Wherever a lake, indeed, occurs, from one cause or another, in the valley of a mountain-stream, it tends to check the flow and to cause a deposition of the material that is carried in suspension. The lake becomes shallower, banks of mud and sand are to be seen beneath its waters, and little reedy islands spring up around the mouth of the main stream. The mouth itself, like that of the Rhine at Rheineck, may become fringed with alluvial banks, which run out like flat breakwaters on either side of its course into the lake. The water washes through these occasionally, and a number of small mouths may arise round about the main one. The general alluvial deposit forms a very shallow cone, like an exceedingly flat fan-talus, its apex lying up the valley and its broad end spreading into the lake. Such a deposit is known as a **Delta**, from the resemblance of its form to the Greek letter Δ. In smaller lakes, like the Toblachersee of Tyrol, the mode of origin of deltas can be very clearly studied; and in our own islands, as at the Upper Lake of Glendalough, in Wicklow, we can often look down from the heights into some black tarn below, and see the grassy alluvium above the upper end stretching on continuously under the water in brown and sandy shallows.

In time these lakes become completely filled up, and an elliptical alluvial flat results, covered with vegetation, through which the river winds. Such vanished lakes, not drained by some catastrophe like the bursting of the Gohna dam, but simply abolished by alluvial action, may be detected again and again in our wanderings, if we continue to cultivate an eye for varying forms of surface.

[1] See Reclus, "Nouvelle Géographie universelle," tome iii, pp. 55 and 60

If we still follow our Tyrolese river down east to the country of the plains, we find the signs of deposition increasing, the signs of cutting-action rare. Soon, perhaps among the woodlands of Styria, the river becomes navigable for pine-rafts, which go swirling down upon its full broad surface, the men straining at long oars to guide them round the rapid bends. And finally the hills about us sink down under long waves of golden corn-land, which stretch eastward in a still hot midland haze; small villages of one-storied houses lie scattered among the fields, connected by irregular and dusty roads. Far away there is a dull panting sound, and we may see a drift of smoke out there across the level sunlight. It is the Danube steamer, journeying southward to Belgrade.

At this point it is well to look back, and to consider the action of our river as a whole. Clearly, it has carved out its own valley, just as the little storm-torrents carve out their grooves ten or twenty feet deep in the loose soils of a hillside (p. 29). The form of the sides of the valley depends upon a number of circumstances, many of which we have noticed as we wandered through it. The beautiful promontories, seen shading off one behind the other, with approximately the same outlines, as we look up towards the valley head, are really parts of the great wall formed by the action of the river, the hollows and combes between them being cut back where tributaries come down from the sides. The general form of the walls, where the rain and the river work together, shows a steep slope in the neighbourhood of the stream, then a more gently shelving region, on which the summer châlets stand among the grassy "alps," and finally the region of the upper rocks, where frost-action assists the driving rain-storms in maintaining a rugged and pinnacled wall of crags. A section (fig. 7), accurately drawn to scale, across one of the steepest pieces of scenery in our islands, will show the general outlines well. The steepest valley-side is here 40°, and others reach as much as 35°, an ordinary stiff slope being about 30°. In the centre we have the crag of Sgùrr Fhuaran, one of the great masses in the west of Ross-shire, 3505 feet above the sea, or about the height of Snowdon. On its left is the hollow of Glen Shiel, and on its right, across another glen, we see the broad back of Beinn Fhada. The construction of such sections, from the

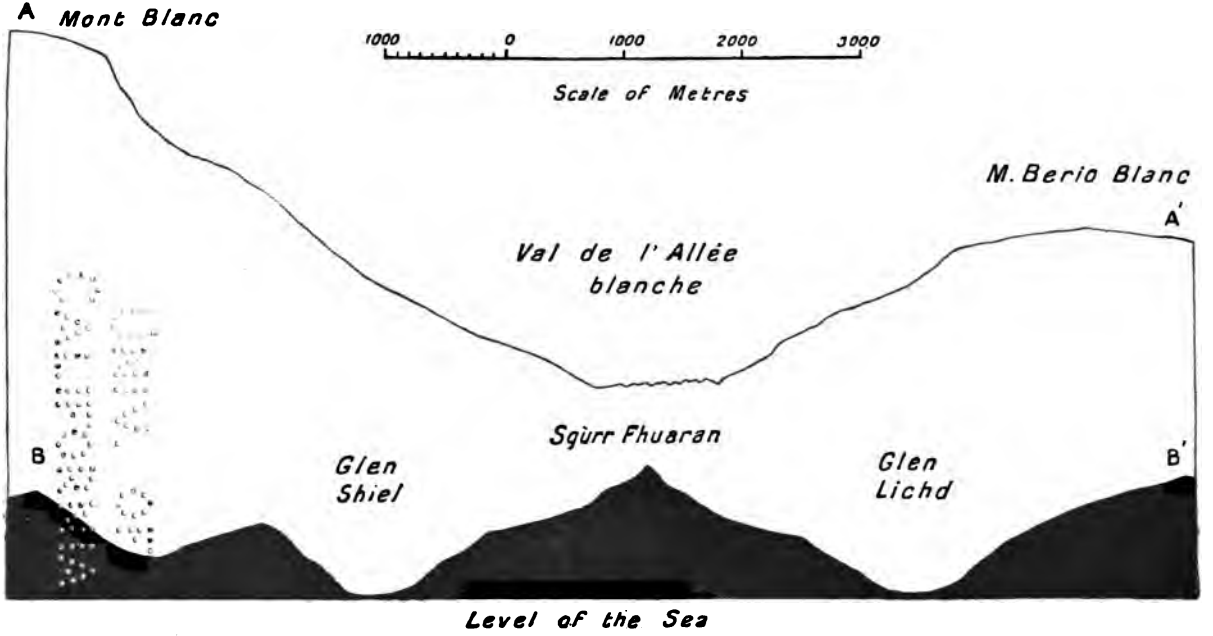

FIG. 7.—SECTIONS showing, A A', the contour of a great Alpine valley, and, B B', that of glens in the Scotch Highlands, drawn to the same scale and with the same datum-line, the level of the sea.

contoured maps issued by various governments, is always a useful lesson in physical geography.

Above this, also in fig. 7, we have drawn, to the same scale, a section across one of the most impressive valleys in Europe, the Val de l'Allée Blanche, on the south side of Mont Blanc. The spurs of the gigantic mountain are set with startling granite pinnacles, or *aiguilles;* but in this section we have passed down a less broken portion of the slope, and have secured the general curve of the valley-side. The highest point on the left is the summit of Mont Blanc, 15,730 feet above the sea; the same sea-level line is used as for the Scotch section below. The dome of snow at the summit ends abruptly in a craggy descent to the gathering-ground of the Glacier du Brouillard. We then descend a very steep slope beside the glacier, which melts away shortly before we reach the valley. The floor of the valley is occupied by the moraine-covered Glacier de Miage, after which we climb a rocky slope and pass along the arête of Mont Berio Blanc. Yet the curves of this wild and magnificent landscape show a remarkable resemblance to those of Sgùrr Fhuaran and Beinn Fhada; the difference is, after all, one of scale rather than of form.

When we speak of rivers performing so much cutting-action in proportion to the slope on which they run, it is clear that some sort of slope must have existed before the river began to run. The course of a stream is primarily determined by the occurrence of a **watershed**, a region elevated, slightly or greatly, above the sea, and sloping down towards it on either side. Water condensed out of the atmosphere on the watershed must flow down one slope or the other; and there may be either a boggy upland along the summit, or a mere knife-edge of jagged rock. You may sit, for instance, on the ridge of Le Chenaillet, on the frontier of France and Italy, and kick stones with one foot into the waters that feed the Adriatic, and with the other into those flowing to the Golfe du Lion. Or you may look down from a knoll in the forests of North-East Bavaria into three great river-systems — the Elbe on one hand, wandering through Bohemia; the Main on the other, a mere affluent of the lordly Rhine; and in the south the hollow of the Danube, already a considerable stream, with 1400 miles yet to run to its delta in the Russian seas.

The watershed once determined, the rivers pick out the lines of greatest steepness; but other circumstances, such as the arrangement of hard strata against soft ones, the folds of the strata themselves, or the direction of the principal joints, come in to modify their course.[1] Soon the slopes become cut into by a series of main valleys, which are joined by lateral ones, branching like the subdivisions of a fern-leaf; and the drainage-system of the country is set up along these well-defined grooves. The action of the torrents and waterfalls of the steeper regions is to cut back the head of the valley; and, as this goes on on both sides of the watershed, two valleys finally meet at their heads and form a notch in the mountain-ridge. Such a depression in the main ridge is called by mountaineers a **col**, and forms a **pass**, or place of passage, for those adventurous persons who prefer to see the world from both sides.

By this cutting back of a valley-head, the river may come in time to look as if it had originally risen on the farther side of the watershed and had forced its way across it.[2] It may even draw off into itself the tributaries that formerly flowed into an opposite river-system; it is only a question of one river cutting back its gathering-ground at a quicker rate than its rival on the other side of the pass.

Other river-systems open up more serious considerations, which can only be answered during one of our later journeys. When we find in any district the channels of the waters passing right across the ridges of the hills, from some source far upon the other side, it becomes a question as to which were in existence first, the rivers or the hills themselves. The fact that mountains may be very modern features will perhaps be impressed upon us when we return some day and examine their internal structure. Meanwhile, if we look round about us in a summer holiday in our own islands, we shall notice in the course of any upland river the essential features that we have studied in the Eastern Alps. On a grassy *col*, with the brown foot-track wandering across it, and the clouds driving up now and again from the hollows before a western wind, we may see the gathering-ground of

[1] For a discussion of the effects of earth-structure on the course of the River Drau, see Suess, "Antlitz der Erde," Band i. p. 339.

[2] *Cf.* R. D. Oldham, "The River-Valleys of the Himalayas," *Journ. Manchester Geogr. Soc.* (1894).

the streamlets, and the black pools of the bog-land draining out on this side and on that, one set of waters going, perhaps, to the Irish Channel and the other to the German Ocean. We may follow down the watercourses through their torrent-stage to spots where they are checked by rocky barriers and deposit their alluvium; and here we are likely to find walls and buildings, the outposts of the highest farms. We may come across valleys, like Glencullen in County Wicklow, once choked with gravel, and now again being cleared out by the stream; and in the lakes and on the lower broader slopes we may see the formation of deltas and shallow terminal fans.

Now and then we may even have excellent models of all these things in a few yards of slimy shore. The clay-beds on the east and west coasts of the Isle of Wight, and, still better, the foot of the cliffs at Cromer, show one in miniature most of the features of river-erosion and deposition. The rain-showers, or the little springs, cut channels in the soft materials, and form fans of the matter which they wash down in suspension. On the surface of these fans the tiny river divides and ramifies, in imitation of the great *débris*-cones of Tyrol. An enterprising child with a spade can soon produce a shallow lake, and can observe how it becomes filled and obliterated by the encroachment of a delta at its upper end. After storms, and often without adequate warning, mud-flows come down the channels excavated by the rills; and thus even the more catastrophic features, the very landslides of the Alps, are reproduced on a convenient scale before our eyes.

CHAPTER IV

ALONG THE SHORE

IT is a fresh morning on the shore, with a light breeze blowing landwards, and the sun marking the broad blue band of open water beyond the shadow of the cliffs, and the white gulls sweeping far away to sea. Right and left the rocks run outwards, with a mile of bay between; and a little river comes down on the left side of the curve, its mouth now deepened and walled in so as to serve as a harbour for the boats. On the same side the cliffs are fairly low, and a fishing-village clusters on them, its successive tiers of white houses being connected by steep lanes and flights of steps. The coast-guard station, with a well-kept lawn before it, and a signal-gun set neatly in the middle, stands on the plateau which forms the summit of the cliff.

On the right, however, the landscape has a sterner air. A bold headland runs out to sea, with rocky islets at its base. The cliff rises some 700 feet from the water, and no sign of a landing-place is visible. The wild-birds have it all their own way there, and even the coasting-steamers do not disturb them, passing as they do outside the farthest islet. A white lighthouse, gleaming this morning in the sun, is planted on that outlying rock to mark the dangers of the channel.

Looking again towards the little harbour, we see that one or two buoys and beacons are set about the river-mouth, as if the entry was not plain sailing; and we may learn that a certain amount of dredging is resorted to, in order to keep the passage clear. Here, in the compass of this mile of bay, we have half the problems of the shore-line of a continent and the sea.

The river, though it is not strong enough to roll along great pebbles, brings down a quantity of sand and mud from the inland country, and has been known to be quite thick and turbulent after heavy rains. At present it looks quiet enough, and we can see the usual deposit of broken china

and gleaming meat-tins lying in the bottom of it under the lowest tier of houses.

However, it has now and then scoured all this out, and cut alarmingly into the pebbly bank, and has even exposed the hard rocks which crop out in ribs farther down the shore. The materials of the floor were freely carried out to sea, to be added there to the growing banks beyond the harbour. Then came a time of gentler deposition, when mud covered up the floor again, and so brought things to their present and more comfortable condition.

So this stream goes on forming its delta, where the current is checked on meeting the broad waters of the sea. Moreover, the deposition of material carried in suspension goes on more rapidly in the mixture of salt water and river-water than it would in the fresh water alone. It is a pretty experiment to take two tall glass vessels, and to fill one with fresh water and the other with water of about the degree of saltness of the ocean. Then pour into each equal quantities of fine dried clay, and stir the mixture thoroughly. In a few hours the salt water will be seen to be markedly clearer than the fresh water, the material in the former case having fallen far more rapidly to the bottom. Hence substances brought in suspension from the land are deposited close to the shores, and are only slowly sifted out farther by the action of the lower currents of the ocean (p. 100).

It is no wonder, then, that deltas in many places, despite the wash of waves on their outer rim, grow steadily forward from the shore; thus, at the wonderful mouth of the Mississippi, the river runs out between banks of its own, as far as some sixty miles from the ordinary alluvial coast-line. The delta of the Ganges pushes itself southward in some fourteen or fifteen tongues, with a total width of about 180 miles; and the Danube similarly makes an encroaching delta at the southern angle of Roumania, the apex of the Δ being fifty miles inland, and the seaward front curving forward in the semicircle which is typical of such deposits.

It is difficult to say how much of Venetia would be left if we were to wash away the deltas of the Alpine streams descending from the north, to say nothing of the enormous deposits of the Po. As we run from Mestre to Venice, the country is scarcely pure land or sea; we are on the very fringe of the alluvium, and the growing banks and islets are

being covered with vegetation, which serves to bind them together, and to promote further deposits when the water brings sand against the plant-stems. It is a strange and melancholy landscape; and we soon realise how the lagoon of Venice itself has been cut off by alluvial barriers from the Adriatic. All these deltas, like our miniature one in the fishing-harbour, grow most rapidly seaward in times of flood and rainy seasons.

The rate at which deltas grow deserves careful consideration, but its determination is beset with many difficulties. When spread over a broad surface, the annual addition to the deposit does not seem particularly thick; and a general survey of the great deltas of the world shows that hundreds of years are required for the deposition of a foot of strata. But such soft materials are continually slipping seawards, and are easily weighed down and rendered more compact by any new layer placed upon them; so that a great addition may be made to them without the level of the general surface rising appreciably higher above the sea. Borings in the delta, such as have been made in sinking wells in Egypt, will, however, reveal the total thickness of the deposit, the earlier layers of which, essentially fresh-water in origin, have sunk far below the level of the sea.

In our bay the tide has now turned, and the boats inside the harbour are already beginning to heel over. In an hour or two the space between the stone breakwaters will be almost dry, except for the stream, which we can then see wandering in the floor. Farther out, brown-pink sand-banks are beginning to appear, the result of the sea's action in throwing back the alluvium towards the shore. These banks, full of land-detritus, and even in part made of the old tins, and broken china, and so forth, carried out in times of flood, are a portion of the true delta of the river. They will be found mapped upon the Admiralty chart, stretching seaward as long tongues and islands, with the straight artificial channel cut in the midst of them, marked by its buoys and beacons.

Doubtless a part of these sandbanks results from the material brought along the coast by the currents of the sea itself. The river-delta has only to thrust out an arm which will obstruct the free sweep of the waters, and tons of foreign sand and pebbles will be quickly planted down

against it. This is a matter into which we shall examine later, when we have climbed along the headland at the other extremity of the bay.

Almost all rivers have their **bars**, produced by the deposition of material from the land on the one hand, and its rejection by the sea on the other. A barrier of pebbles and other detritus is formed across the mouth of the stream, and is often impassable for boats unless the tide is high.

All these banks and barriers, in which both the river and the sea have played a part, come under the head of **estuarine deposits**. Sometimes the fresh water prevails against the sea, and true river-strata are laid down; these beds, like the deltas formed in lakes, are called **fluviatile deposits**, those formed by the sea itself being styled **marine**. In the one series, the shells of animals that live in fresh water will be found, to prove the mode of origin of the strata; in the other series, marine remains, seaweeds, &c., will be embedded. In any estuary, leaves, and twigs, and even large trees, will be washed down from the land, and will become covered up and preserved in both the marine and the fluviatile deposits.

So far we have considered only the material brought down by our little river in suspension; but we may be sure that its waters contain a good many chemical substances in solution. If we boil off a filtered sample of the water in a clean test-tube over a spirit-lamp or a gas-burner, we shall obtain these dissolved substances, which are left behind as a white or creamy film clinging to the bottom of the tube. Probably calcium carbonate is present in the greatest proportion, while combinations of magnesium, sodium, potassium, iron, &c., will also occur, including common salt, or sodium chloride.

Now all these dissolved materials pass through the sand-banks, and over the bar, into the great sea unaltered. Some are laid hold of by those unconscious analytical chemists, the fishes and the molluscs and the sea-urchins, and other living creatures that abound in the waters, and are extracted by them to form their skeletons and shells and strengthening plates; others simply go on accumulating in the sea, which is salt accordingly, and is not fresh like the water when it first descends from off the hills.

The "fresh" water of rivers is of course salt in some

degree, but so slightly that we do not notice any taste in it. It is only because of the great gathering of chemical salts in the sea that we find it has a characteristic taste, which is chiefly due to sodium chloride. This substance occurs in ordinary rivers in the proportion of about .0035 per cent. of any given weight of the filtered water, *i.e.*, of the water with the suspended substances removed from it; but in the sea it forms 2.8 per cent. of the weight. The total salts dissolved in river-water may equal .04 per cent. by weight; but in the sea they may be as much as 3.5 per cent.[1]

If we evaporate off the water, and weigh out 100 grammes of the mixed salts that remain, the proportions of these are found to be as follows:[2]—

	Per Cent.
Sodium chloride	78.32
Magnesium chloride	9.44
Magnesium sulphate	6.40
Calcium sulphate	3.94
Potassium chloride	1.69
Other substances, including calcium carbonate and silica	0.21
	100.00

We must remember that the oceans may have been salt from the time of their first formation on the globe; but their saltness must have been largely increased by the enormous amount of material steadily brought down in solution from the land. The air is continually absorbing pure water by evaporation from the surface of the sea, and the layer from which this water is withdrawn becomes in consequence more highly charged with salts. Salt water has a higher specific gravity than pure water; and hence the surface-layers are constantly sinking, while other water of less specific gravity rises from below. This process, by itself, keeps up a slow circulation in the waters of the ocean. Rain, on the other hand, forms a layer of fresh water on the surface of the sea, which floats there until gradually mingled with the salt layers below.

Near the mouths of great rivers the sea-water is naturally less salt than in the open ocean; and seas with

[1] See, for example, the analyses given in Huxley's "Physiography," pp. 125 and 128.

[2] Krümmel, "Der Ozean," p. 94.

narrow communications with the ocean become practically like great lakes, and are far fresher than the average. Thus the northern waters of the Gulf of Bothnia contain only from .10 to .15 per cent. of salts, a figure increasing southwards and westwards to .86, 1.65 (at Kiel), 1.9, and finally 3 per cent. in the Skagerrak. Outside, in the North Sea, we have 3.3 per cent.[1] Sea-water with 3.5 per cent. of salts has a specific gravity of 1.027.

We have as yet left out of count the air dissolved in sea-water. This is caught in among the dashing waves, or is brought down by the rain, and allows the living creatures of the deep to obtain oxygen for their breathing. In the upper layers of the sea, at all events, the volume of oxygen absorbed is to that of the nitrogen as 35 is to 65 (see also p. 40). Air occurs, owing to the circulation of the ocean-waters, included even in the greatest depths of the sea; and the colder the water, the more air is it likely to contain.

If we wait until the tide again turns, and the line of foam, where the waves break upon the sandbanks, draws nearer and nearer to the shore, we shall be able to watch the work of the sea against the dark headland on our right. As we walk across to it, over the loose and rolling shingle, the dull boom, as of a distant gun, comes to us already. The water has reached the farther points of rock, and is bursting upon these obstacles with a shock at every line of rollers; and, before we hear each sound, we can see the spray rising in sudden clouds into the sunlit air across the bay.

If we hurry on, we shall find those outlying rocks not yet surrounded by the water. We come under the shadow of the enormous cliff, and clamber over great angular blocks that have fallen from it. Then we reach ribs of rock running out seaward (Plate IV), with a little sand caught here and there between them. Red sea-anemones lie, like lumps of jelly, in the pools, and parts of the rocks above the level of low water are covered with close-set barnacles and limpets and periwinkles, which are thus left dry twice a day. And so we come to the pinnacles and bluffs of rock that will soon form islands at high tide.

These **sea-stacks** looked small when we were over there in the harbour, for above them rose the frowning greatness

[1] Krümmel, "Der Ozean," p. 97.

of the cliff. But they really are a hundred feet or so in height, and are composed of stratified rocks, of materials disposed in layers, like those forming the base of the cliff itself. The beds are tilted up in places, like a pile of books that has been thrust over sideways; and the upturned edges form ribs and ridges when worn down to the level of the shore. Such ribs we have already noticed on our way out.

The great waves are now nearing us in force, breaking on the seaward face of the stacks and booming in their crevices and caves. Let us climb up the ledges of the rock above us and look over towards the sea.

The summit is fairly smooth, like a sloping table, being formed by the surface of one of the gently tilted strata; and across it runs a huge cleft, down which we can look to the very base of the sea-stack. On a ledge in the half-darkness, higher than the ordinary spray, a few sea-loving ferns have clustered; and one or two tufts of grass have actually established themselves on the inclined table on which we stand.

As we look down, there is a sudden swirl and rush below us. A roller has just burst on the sea-front, and the crest of the wave has fallen, and has flowed on like a torrent into the cleft. Its foaming edge laps into every seam and crevice; the tongue of water breaks on the closed end of the cleft, and springs towards us in a cloud of angry spray. The roar of it spreads far across the bay; it was this sound that we heard as we left the harbour. Then the water drains out again, for the tide is not yet high enough to keep the floor of the hollow full; and we hear a grinding sound, as the pebbles down there are being dragged seaward one against the other.

From one of the ledges below us the water flows out even after the floor is again left bare; clearly some hollow must have been carved out above it, into which each wave can penetrate. If we creep to the very edge of the stack, where it goes down sheer into the sea, we shall learn further as to the irregularities in its wall.

On one hand the stack sends out a promontory, and we can see the side-face of this, with the strata running across it like sloping bands. Under some of the ledges formed by them, long hollows and caves occur, roofed by the bed above; and pebbles and boulders lie in these depressions. As each wave breaks, these caves are flooded, and the stones are flung inward against the farther wall. A swirling movement again

takes place as the water retreats, and each time destructive work is done. The sea, with its tremendous battering-power, is excavating caves, just as the streams make pot-holes; only the action is horizontal, rather than vertical, the water lashing like a whip around the flanks of the sea-stacks and islets.

The cleft near us is only a widened joint, one of many that run across the mass; and the form of the whole stack is largely influenced by them. The constant attack of the spray helps the rock to decompose; films of crumbling alteration-products are formed on the surfaces of the joints; and blocks become finally unsteady and fall into the widening gully. Down below, the sea uses much more effective means; the fallen masses, as well as the pebbles swept in from other sources, are laid hold of as battering-tools and are hurled against the rock; and thus a cave is formed, wide and shallow at first, but continually deepening, its roof often falling in and producing a very marked ravine in the sea-stack. Our cleft has doubtless become wider by the removal in this way of supporting masses from its base.

Out beyond us, quite surrounded by the incoming water, is a stack which is bored through completely by an arch, as bold in its proportions as that of a cathedral-transept. The cave-cutting action has here drilled the mass through to the other side, and it is only a question as to when the roof will be so far weakened as to fall. In that case one pillar of the arch will form a new stack or sea-pinnacle, which will become all the more isolated from the main mass as the sea continues to work round it.

This is the history of the tiny islands round about each of the main stacks; over many of them the sea now flows freely at high tide, and as many more must be permanently below its surface. Every fall of rock furnishes the dashing breakers with fresh and unworn tools; every grinding of one mass on another supplies sand and grit, which smooth the surfaces and enable the water to slip on uninterruptedly to further conquests.

As we look out towards the lighthouse upon the most distant isle, we realise that the dangerous reach between it and ourselves is filled with the worn-down stumps of islets and the wreck of huge stacks of former days. All this region was once part of the solid land behind us; the islets were once united as a great promontory stretching a mile to

seaward; and the waves have worked their will with it, cutting it up into squares, like a regiment overwhelmed by cavalry, and then attacking the bluffs separately, so that the whole will in time inevitably disappear. When our eye has got used to them, we can detect the beginnings of caves and natural arches in every exposed face round us; and beneath us we have the voice of the invader, triumphing in the darkness of the clefts.

The spray now rises too near us, and is flung by the wind across the seaward face. We must descend to the little sand-spit, which still finds shelter behind the stack. There is very little of it, and the pebbles stuck into it are mostly derived from the stack itself. Soon the sea will lap round and cover it, and will some day shatter its protector and sweep the spot clean and clear, down to the more resisting ribs of rock below.

These ribs of rock now represent for us the ruins of the older headland. When we have crossed them again, among the barnacles and seaweeds, to the foot of the great cliff, we can look back and watch the sea racing in over them, wave upon wave, and rattling the pebbles across their upturned and worn-down edges. Here and there a big stone lies, resting on two adjacent ribs, and ready to be moved, in days of serious storm, as a formidable assailant of the rocks. As the tide comes in across this shelving surface, we see how the waves lose their force; but they still have strength to burst upon the great rock-wall, when the water rises to its fulness. If, as we saw among the stacks and islets, the bulwarks of the shore are being cut away, the sea will be able to stretch farther and farther inland, instead of merely spreading over the *débris* to a line along which it is at last powerless to act.

In fact, a gently sloping surface is being formed by the action of this great horizontal saw—an old familiar comparison which cannot easily be bettered. And the dragging of the loose blocks and sand over this surface is continually wearing it down upon the seaward side, and enabling the inner edge to encroach slowly upon the land.

Such a surface was called by Sir Andrew Ramsay a **plain of marine denudation**; the title is a long one, but is far more expressive than the attempts made in some sciences to cover up each conception in a single word of

Greek. When we view from some distance the sea rolling in across such a plain, especially when the great green waves are driven by a stiff gale upon the coast, we may indeed wonder how any bars of rock survive at all above the surface (Plate IV.).

We look round at the curve of the bay itself, and we see that the water is now high upon the beach of sand. Over against the village it is beating on the little promontory, and filling the harbour, foaming against the piers. At spring-tides, and in stormy weather, we know how the waves extend right up to the low cliff that runs all round the bay; and we can realise now that this curving indentation, a mile across, is also a product of sea-action. The bay itself is only an extended form of the hollows cut in the face of the sea-stacks.

The general tendency of the sea's attack is to excavate wide sweeping inlets. It cannot go on indefinitely surging up a narrow channel; the mouth becomes cut away on each side and widened, and the broad flow of the waters forms a semicircular **bay**.

Some of the most interesting examples of this action are to be seen in the "*coves*" of Dorset. A bed of hard limestone forms in places, such as Lulworth, the bulwark of the land; and behind it are other limestones, sands, and clays, and then the soft massive limestone known as chalk. The battering of the sea makes holes and channels through the barrier; and then the water, meeting with weaker materials, carves out bays behind it. It will be long before the more resisting barrier of Portland stone is worn away, so as to leave these "coves" properly open to the sea. When this happens, several smaller ones will probably unite quickly, and will form one broad sweeping bay.

The loss of land before the sea is often so rapid as distinctly to affect the towns and farms along the coast. The military road and the footpaths along the south cliffs of the Isle of Wight are always liable to disturbance, and the difficulties are much increased by the rapid cutting back due to fresh-water streams as they fall over the soft sandstone wall. At Cromer, in Norfolk, where the loose pebbly cliffs lend themselves so well to the formation of model deltas, the sea rapidly undercuts the material and causes the coast-line to recede some six feet annually. Churches of known

THE SEA BREAKING ON A ROCKY COAST, NEAR BALLYCASTLE, CO. ANTRIM.

The foreground is formed of upturned Carboniferous strata, which are being worn away by the formation of a plain of marine denundation. Fair Head in the distance.

PLATE IV.] [*Photographed by* Mr. R. WELCH.

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date have often served as a means of measuring the amount of marine denudation in the course of several centuries; and many on our eastern English coasts have gone over altogether into the sea.[1]

Mr. Henry G. Spearing[2] has observed that on the exposed face of Bideford Bay, where Westward Ho stands, the sea has recently removed the land at the rate of about thirty feet a year. The coast in this case is of course formed of soft materials, and a new cliff twelve feet high has been cut at one point in the clays.

Similar "invasions" of the sea, so rapid as to seem like floods to the bewildered and unobservant inhabitants, have cut away the sandy south-east coast of Kent between the Roman period and our own, depriving us of a strip of land nearly four miles wide. The story of the loss of Earl Godwin's estates is probably a true one, and the Goodwin Sands to this day are dangerous banks upon the site of the eleventh century shore-line. The slips at Sandgate[3] in 1893, and those common on the Antrim coast, show how the action of springs among permeable strata conspire with the sea to bring about the destruction of the land. (See p. 72.)

It is a somewhat melancholy reflection that the scour of the waters in the English Channel is widening the Straits of Dover on both the French and English sides, and this at the rate of about a yard per annum. Belfast Lough is also growing, as is shown by the approach of the three-fathom line, marked on successive charts, to the coast-towns upon either side.[4] But the artificial protections set up along the sea-face of most of our coast-towns do much to preserve the cliffs behind.

The huge black cliff under which we are still standing towers vertically for some 700 feet; and a number of causes work together to maintain this magnificent sea-front. The rock is massive, and has strongly developed vertical joints; frost, in our climate, occasionally splits off the upper blocks, as it does among the cirques of the mountains; and the sea is sufficiently powerful to break up and remove the fallen

[1] See H. B. Woodward, "Geology of England and Wales," 2nd edition, p. 594, &c.

[2] *Quart. Journ. Geol. Soc.*, vol. xl (1884), p. 474.

[3] See *Nature*, vol. xlvii (1893), pp. 449 and 467.

[4] Miss M. K. Andrews, *Irish Naturalist*, 1893, p. 47.

masses, so that they afford no real protection to the base. The waves are always undermining the huge wall, and bringing down vast slides of rock along the joint-planes; the talus-blocks are gradually broken up, and become worn down into mere pebbles, which serve to scour out and deepen the sea-caves. On looking up the face of the cliff, it is not difficult to see whence the recent falls have come, by the fresher nature of the scars that they have produced. And a still more striking spectacle awaits us if we ascend to the summit by way of the gentle grass-slopes in the rear.

The beach is now nearly covered with the water, and we can leave it until a more favourable occasion. When we reach the higher ground, we can see, as in a map, the distant headlands jutting out, north and south of us, with curving bays between them. All along the coast we have evidence of the aggressive nature of the sea; and the forms of these promontories and indentations, which at first seemed designed for our affliction during our early studies in the school-atlas, now begin to have a new meaning; we find that every sea-cove has an interesting lesson of its own.

Here, among the tufts of grass and heather, we must walk carefully towards the edge of the great cliff. As we do so, we cross several deep gullies, running roughly parallel with the sea-face. A little observation shows us that we are here present at the birth of mighty landslips; and the ground is already prepared to give way beneath our feet. The enormous rock-mass is fissured by its joints, and the removal of material from its front and base causes flakes, as it were, consisting of thousands of tons of material, to slip outwards and ultimately to fall. Thus the cliff-face may recede suddenly at certain points by several feet in a few seconds; the nobler the scale upon which it is developed, the more liable it is, like a lofty mountain, to catastrophes and sudden denudation.

Thus it is by no means only the softer strata that suffer rapidly from the battery of the sea. The sandstone isle of Heligoland[1] is thus a mere fraction of its former size, as recorded in historical documents, perhaps only a quarter being now left; and a neighbouring island, the cliffs of which were nearly 200 feet high in the seventeenth century,

[1] Reclus, "La Terre," 3me édit., tome ii, p. 192.

nas practically disappeared, leaving only long ridges of blown sand. Now that accurate maps have been constructed, showing the coast-lines of most countries, it is surprising to note what changes occur in a hundred or even fifty years.

Our great headland may have formerly been part of a hill situated far inland; the present grass-slope falls towards the land, showing that more than half the mass has been cut away. The highest point is, in fact, upon the very summit of the cliff. Farther down the coast we can see a hill, the base of which is just being attacked; a low cliff has been carved out of it, and the ground rises from the edge of this to the summit of the hill, a mile or so inward from the sea. Again, on leaving Newhaven, in Sussex, by the steamer for Dieppe, a number of grassy combes are seen breaking the line of the chalk cliffs, and terminating half-way up them above the sea. These represent old valleys which once ran down to near the sea-level; but the white cliff has been formed across them, leaving only their higher regions facing us; and in time these evidences of the old form of the land-surface will no doubt entirely disappear.

So some cliffs grow higher as the sea causes the coast-line to recede; others, like our great one, will become less and less important. As the sea advances, it will meet with various irregularities that have been already carved out by rain and rivers on the land-surface; and the form of the coast may thus change quite abruptly, while the flow of the tides and of the permanent currents may be interfered with in a striking manner, through the sea having to accommodate itself to indentations for which it is not at all responsible.

So far we have regarded only the denuding action of the sea. Enormous quantities of material are annually removed from the coast in certain regions; and M. Marchal has given us the figure of 10,000,000 cubic metres[1] as the amount taken each year by the English Channel in the neighbourhood of Kent and Normandy. That is equivalent to a bank of rock a mile long, 300 feet in width, and about 223 feet in height. Now, all this material must go somewhere; for only a small portion disappears in solution in the sea. The same agent that destroys so persistently in one place may, like a river,

[1] Reclus, "La Terre," 3me édit., tome ii, p. 175.

transport the *débris* to another area, and there peaceably construct new land.

As a matter of fact, many of the pebbles formed by friction from blocks that have fallen into the sea, and part of the finer sand thus produced, are continually travelling along the coast. Much of the material no doubt runs down the steeper seaward face that bounds the plain of marine denudation; here it finally escapes from the action of the waves, and is only slightly affected by the permanent currents of the sea. It thus forms a broad submarine talus, a shoal which covers up the old surface of erosion, and which stretches some way towards the true oceanic floor. At its upper edge the material is worked on by the breakers as it slides outwards from the coast, and the finest substances, the tiny particles of clay, become sifted out from the sand-grains and are washed away to far greater distances. The sand is, moreover, in part separated from the pebbles and from the small unrolled rock-fragments, and is removed to an intermediate distance. Thus the *débris* of the cliffs undergoes a steady selective process, like the materials at a river-mouth. We have pebble-banks formed typically near the shore; then sand-banks farther out to sea; and deposits of fine mud beyond these, the last named occurring even at depths of between 1000 and 2000 fathoms. The mud will consolidate as stiff **clay**, or, if it preserves a stratification and splits into fine layers, it will form the rock known as **shale**.

Local formations on the coast will interfere with the regularity of such deposits. Thus, near the mouth of a muddy river, clay-banks will accumulate close to the shore itself; there is too great a supply for the sea to carry off. Enormous sand-banks, again, devoid of coarser fragments, may be formed close under soft sandstone cliffs; for this rock breaks up so readily that no true pebble-beach can arise. As usual, each locality will give us some special features of its own, and will provide interesting modifications of the general plan of shore-deposits.

A mingling of one deposit with another on the same horizon must always occur, due to the imperfect sifting. Thus pebble-beaches graduate into pebbly sands, and sands into sandy clays, known as **Loams**.

Clays, again, often contain a large proportion of calcium carbonate, due to the shells included in them. When the

proportion amounts to one-third of the total weight or more, the clay becomes almost a clayey limestone, and may be called a **Marl**.[1]

We can, fortunately, study these formations in many places between high and low water-marks. There are regions where the sea confines itself to laying down new material; where the scour of the currents only serves to bring substances in suspension from other places which are being denuded; and here, then, the land grows by a process opposite to that of the formation of a delta. The additions to the coast are, in fact, the deltas of oceanic streams; the carrying power of these currents is reduced when they strike upon projecting land.

For such deposition a quiet area is indispensable; a ridge exposed to storms will be despoiled of any material that may have been laid down upon it in quieter times, just as a valley may be kept clear by recurrent flood-periods in its torrent. The shifting form of estuarine banks, and of other products of denudation along a coast, may easily cause a bay to receive deposits during one series of years, and may then allow it to be swept clear again during another series.

In the hollow of our own little bay, beginning in the shelter of the great rock-headland, and running round towards the harbour, we find an area in which marine denudation is at present at an end. The cliff once cut out is becoming covered with soil-slips, and is in places grass-grown; and its form is already so much altered that a winding cart-track has been made across the face of it, by which rough vehicles are led down for the gathering of seaweed on the shore. At its foot are banks of pebbles, untouched by the water except during those storms that happen to coincide with the highest tides of the month. Beyond them stretches a gently sloping and pebbly beach, the stones becoming gradually fewer and fewer as we go seaward, until we come to the zone selected by the bathers, where all is fine and shelly sand. We must come down as the tide is going out, and view this second, this accumulative aspect of the sea.

The highest ridges of the beach, forming terraces under the old cliff, result from the transporting power of the waves

[1] This is the true sense of the word "Marl," as adopted from agriculturists, though the term is often much misused. See J. Macculloch, "A Geological Classification of Rocks" (1821), p. 630.

during exceptional storms. The dash of the water under these circumstances carries out any sand again, but leaves the pebbles hurled up one upon the other. They lie there with their flatter surfaces fairly horizontal; but, apart from this, there is little appearance of stratification. In one place a slip of peaty soil from the top of the old cliff has spread out and formed a layer, containing rootlets and a few potato-stalks, on the surface of the pebbly terrace; and fresh pebbles have already been flung on to the top of it, so that it is likely to form a distinct stratum in the beach. When finally consolidated, we should call the pebble-beds **conglomerates**; and the black earthy layer in between them would be said to be *lignitic*, or full of woody vegetable remains. Any stems of trees or pieces of broken fencing that have been brought down with it would become converted into a deep brown or black substance known as **lignite**. The gaseous products of their decomposition pass slowly off, the combinations of oxygen, hydrogen, and nitrogen being more freely formed than those of the carbon; hence the latter constituent rises in proportion in the residue, and forms more than 60 per cent. of lignite.

Flaky shells, easily lifted by the waves, are found here cast up with the pebbles and entombed among them. Oyster-shells thus often predominate; but we must be careful to avoid places where the fishing-people have thrown out their rubbish-heaps, for quantities of molluscan shells are sure to occur in these, and may have been brought artificially from some distance. But an examination of the pebbles themselves will give us a good idea of the work of the sea as a common carrier.

A layer of corks may occur on the surface of the beach; these accumulate in the areas of deposition from the daily passenger-steamers that go up and down the Channel. Cinders from the furnaces are also frequent; and these two sets of objects remind us how anything which floats without easily becoming waterlogged may be carried indefinitely about the world upon the surface-currents of the ocean. Seeds of strange plants have thus been conveyed from one country to another, and have occasionally found suitable soil, and have added permanently to the vegetation of their new home. Man himself has often been similarly distributed, much against his will, being carried in canoes before the

great continuous winds, and landed, perhaps, on an unknown shore to form the first population of a continent. These ugly little banks of corks are thus not to be despised; observations of such trivial objects may help us to determine the direction of the great ocean-streams.

But the pebbles are more distinctly interesting. Elderly ladies and gentlemen, who come down here as summer-visitors, spend hours in collecting them, on account of their very variety and beauty. A great number of them come from the waste of the sea-stacks and the grim dark headland yonder; they are already admirably worn and rounded, and we see how the daily friction smooths and grinds down even the hardest rocks. But here is a bright red pebble, a jasper, unlike anything in the solid walls of our own bay; and all around are others made of hard altered sandstone, called "quartzite," the nearest mass of which lies some twenty miles away to the south. Here, again, is a green and black pebble which we cannot easily identify; but our mineralogical friends may make a microscopic section of it, and may tell us that it is from a unique mass occurring on the coast of Norway. Such a specimen has probably been brought here on a block of floating ice, in days when these seas were colder or when currents ran in other directions than at present. Trees that have fallen into the sea may also bring foreign stones entangled in their roots; and many seaweeds cling to stones on the sea-bottom, and, when torn up by storms, carry these specimens about with them to long distances.

It is not a matter that must be dealt with lightly, this tracing of the place of origin of pebbles gathered on a beach; and we must remember that they may have come from some outlying and even adjacent point which has been worn entirely away. The nuggets of gold in the rivers of South America, and, it is said, the famous diamonds of Golconda, serve to illustrate this point. They occurred freely in the alluvial deposits of the rivers; but a search for them in the rocks up the valleys has proved disappointing, their original matrix having been denuded off the face of the earth.

But, in the case of the pebbles of quartzite on our beach, the evidence is pretty clear, and a walk south along the coast confirms our first supposition. The pebbles are re-

placed by huge boulders as we reach the actual promontory of quartzite, and the sea is evidently still maintaining the supply. All along the intervening coast, in every sheltered inlet, pebbles from this same source can be found; and clearly they are still being swept round our great headland into the quieter waters of the bay.

Some of the pebbles on our beach are thrown up from the estuarine deposits, and were already rounded by the stream before they came into the sea. Just as when torrents empty themselves into lakes, so beds of marine conglomerate often arise, in which the only part played by the wider waters is the smoothing out and spreading of material which has been already rounded.

In conglomerates very few shells are found, because, in the first place, the molluscs cannot live amid the pounding action of the pebbles; and because, in the second place, any dead shells that are washed in become speedily reduced to powder. But farther down the beach, where the finer sand stretches, abundant shells may be discovered, together with dead crabs and other shore-animals, which become buried as the mass accumulates. The smoothing and stratifying action of the sea is apparent in the even surface of these sands; every tide, the wash forward and backward of every wave that breaks, tends towards a spreading and a distribution of the material, and uniform **strata** are thus deposited over wide areas of the coast. Between the tides, we may note how the water has here and there raised the sand into ribs and delicate ridges, **ripple-marks** as they are called, the particles of sand being pushed forward in one direction like a wave, and then dropped where the water could no longer sustain them. The sea-salt may dry on the surface of these when they become exposed, and will tend to make the structure firmer. The sun also, drying the material, causes cracks to open in the sand or mud of the beach; while the ebbing tide, running out round little stones, forms grooves and tiny channels in the deposit. Man, moreover, and other animals leave footprints and tracks as they pass over the yielding surface.

Current-bedding, like that of river-gravels, must clearly occur in places, especially where changes in the deposits at any point alter the direction of the currents; but marine deposits as a whole are more regular than those produced by

any action on the land, especially where the material is spread out at some distance from the coast. A change in the direction of the transporting currents, in the material supplied by local rivers, or the fact that the sea has begun to attack some rock hitherto beyond its reach—any of these occurrences may cause the deposition of a new stratum of different mineral character to that preceding it.

Sea-sand is so familiar, ever since, as children, we dug in it with wooden spades, that the variety of its constituents is hardly suspected by us. But it is well worth while to fill a box with the material and to bring it home for examination.

The best instrument to aid in this examination is a sieve. If special ones are not to hand, sieves may be made by knocking the bottoms out of wooden boxes about 6 inches square, and fastening muslin of various degrees of fineness on to the sides instead. But it is very useful to have a set of 6-inch circular chemical sieves, costing altogether about 8s. 6d. Three sieves of brass-wire, with meshes containing respectively 30, 60, and 90 holes to the linear inch, are fixed in tin cases, and are so made that they will fit into one another, leaving spaces some $2\frac{1}{2}$ inches deep between. The coarsest sieve lies at the top, and a cover fits upon it; beneath the finest, again, a tin dish fits exactly, to catch whatever particles get through the 90-hole mesh. The whole set now forms a cylindrical box, crossed at regular intervals by the three wire nets. If it is necessary to sift even the fine dust that has escaped into the lowest dish, an extra sieve can be made of very fine silk, and the finest particles of all can be washed through this under a water-tap.

Let us take a handful of our sand and leave it over-night in a basin of water, to cleanse it from the sea-salt that has been deposited upon it. We must now dry it thoroughly—an oven will do for this—until the particles no longer stick to one another. Then we pour it upon the uppermost sieve, put on the cover, and shake the whole set of sieves from side to side, with the addition of a circular motion.

In two minutes or so a complete sifting will have taken place, according to the coarseness of the materials. Let us separate the sieves from one another, and pour out their contents into little card-trays, putting a number in the bottom of each to distinguish them from one another. The top sieve contains all the constituents that are more than

one-thirtieth of an inch in diameter. Here are little stones, which are the smaller pebbles of the beach, and flakes of broken seaweed, and fair-sized fragments of shells, and a few perfect shells, the small size of which has enabled them to escape destruction. One or two delicate glassy-looking rods are the spines of sea-urchins, and are seen, when examined under a low power of any common microscope, to be ornamented all over with ribs and little projections. Probably the second sieve contains a larger quantity of material, and here we find much the same constituents as in No. 1, only they are of smaller size. The most interesting objects are the minute coiled glassy-looking shells, almost all perfect, which can be well seen under a microscope magnifying about 25 diameters. They are perforated by minute holes, and consist of numerous chambers, like the well-known shell of the pearly Nautilus. These are the shells of *Foraminifera*, some of the humblest animals on the globe, the jelly-like bodies of which are capable of forming these complex structures out of calcium carbonate, the materials being derived from those in solution in sea-water. Other dull white and practically opaque foraminifera are likely to be seen, and can be identified and named by comparison with the figures in special works upon the subject.[1]

The minerals derived from the friction of the various pebbles are found fairly separated from one another in this sifting; that is to say, few entire pebbles have come through, the particles allowed to pass being so small that each consists typically of one mineral alone. In sifting No. 3, where the grains are between one-sixtieth and one-ninetieth of an inch in diameter, most marine sands will yield a material consisting of very well-divided mineral particles.

Scarcely any shell-fragments now remain, and quartz is clearly the predominant substance. Its hard grains, with vitreous lustre and irregularly curved surfaces of fracture, gleam like little lumps of glass under the microscope. Black minerals are probably also present, and some can be lifted out with a magnet, showing the presence of magnetite. The others may be hornblende, augite, tourmaline, &c. Tiny flakes of mica may also be seen, some silvery, some a rich bronze-black. If we wish to extract any particular grain from the heap as seen under the lens, the point of a fine

[1] See H. B. Brady, "Report on the Foraminifera," *Challenger Reports*, 1884.

colour-brush or of a sharpened rod of wood, just moistened, will serve to secure it, and it can then be lifted out and dropped off into water upon a slip of glass or in a watch-glass for chemical or other treatment (see p. 23).

The dust in the bottom pan will probably be too fine for convenient study; but the vast bulk of it can be seen to consist of quartz. As sieve No. 3 and this pan contain almost all the sand put into the uppermost sieve, it is clear that, when the shells are deducted, the chief constituent of our sea-sand is simply quartz. The grains, being so small, are very little rounded, and their practically indestructible character makes them survive most of the other minerals that may have originally been mingled with them. Doubtless any clay particles have been sifted out long ago by the action of the waves, such bodies being sometimes so minute that 17,000 of them might be arranged along a single inch. A sand left to itself in the shallower portions of the sea, without the addition of new shells or of matter from the land, would tend to become more and more purely a bank of colourless quartz-grains.

Sometimes a foraminiferal shell is found which is filled with a soft green earthy substance, easily crushed between two glass plates or under the blade of a knife. This is **Glauconite,** a hydrous silicate of aluminium, iron (in the condition of peroxide), potassium, magnesium, and calcium.[1] Its precise mode of origin is obscure; but Messrs. Murray and Renard, in the report quoted, believe that it arises partly by chemical changes, which go on between the dead organic matter within the shell and the fine mud that has oozed into the chambers, and partly by absorption of substances, such as potash, from the sea-water. The glauconite in any case grows until it completely fills the shell and even bursts it;[2] and, if the shell breaks away or becomes dissolved, the material is set free as a green grain which is a cast of the interior of the foraminifer.

We shall find these grains thrown up only sparingly on our coasts; but they are formed abundantly at a little distance from the shore, and mostly at a depth of about 100 fathoms. In many old sandstones and limestones they form a great part of the rock, giving us *Greensands* and *Glauconitic limestones*, and showing that the same complex

[1] For recent analyses, see "Report on the Deep-Sea Deposits," *Challenger Reports*, 1891, p. 387.

[2] *Ibid.*, Plate XXV.

chemical processes went on, as now, when those materials were being deposited.

It is obvious that in our walk along the shore we are only on the threshold of all the wonders of the deep. The deposits of soft separated mud, for instance, will be found in their purity farther out; they form the bottom of the deeper portions of all land-locked seas, but rarely extend in the great oceans to 500 miles from the coast. The materials carried in suspension by the sea as products of denudation of the land are, indeed, mostly deposited as a fringe some 150 to 200 miles wide round the continents, forming thick banks along the coast itself, and becoming thinner and thinner down the slope to seaward. Only bodies that can float, such as volcanic ash and lumps of pumice, which are full of cavities, find their way far enough from shore to sail over the real oceanic depths. Here they may become decomposed and waterlogged, and may thus sink, to be deposited in the uttermost parts of the sea. As a rule, the only deposits found by dredging operations after 2500 fathoms (15,000 feet) are due to animal and vegetable life or to this decomposed volcanic material. Thus the sea-bottom at one of the greatest depths ever accurately sounded was found to be covered with the skeletons of organisms that take silica from the sea — **Radiolarians**, certain **Sponges**, and the humble plants called **Diatoms**. The depth was 4475 fathoms (26,850 feet), and the sounding was made east of the Philippine Islands, and about one-third of the distance between New Guinea and Japan.[1] The mineral particles in this deposit were derived entirely from volcanic rocks, or from meteorites coming from outside our own planet.

We must not venture away to sea into these fascinating regions; but we may enquire where it is that the shell-fish, whose remains we see cast up so often, find their most agreeable dwelling-place. They may live close in to the coast, if no rivers are discharging *débris* upon them. They choose the purest waters, consistently with the presence of a constant food-supply; and all the familiar genera live at depths less than fifty fathoms. Where conditions are favourable, their shells accumulate, as the animals die, in vast banks, sometimes formed principally of one particular

[1] "Report on Deep-Sea Deposits," *Challenger Reports*, p. 204.

species. The constitution of the shells is calcium carbonate, either in the form of calcite or aragonite; and hence beds of **Limestone** are being formed to-day by the accumulation of shells beneath the level of the sea.

Calcium carbonate being soluble in water containing carbon dioxide, it is not surprising that the sea itself, with its included gases, attacks great heaps of dead shells, and removes their surface-layers, or even dissolves them altogether. The carbon dioxide is in great part derived from the decay of animal matter in the sea, and its solvent power is increased at great depths by the pressure of the overlying layers of water. Meanwhile, the currents are always washing the shell-bank out at its edges, and rubbing the remains together, producing a fine *limestone-mud*. The water, charged freshly with calcium carbonate in solution, wanders through the mass, and helps to cement many of the fragments together, a re-deposition of the dissolved material taking place. Calcium carbonate is also deposited when fresh water strongly charged with it comes in contact with saline waters.[1] The chemical reactions that take place are not yet clearly known; but it is certain that stones and shells may become cemented in our harbours by dense deposits of chemically formed limestone.

The limestone-mud and the tiny foraminiferal shells also get washed inside the larger shells and completely fill them; and thus the foundations of a solid bed of limestone are laid down. This bed, like the sand-banks and mud-banks, will be thinner at its edges, ultimately dying out all round, and will be thicker in the centre, below the point where the living molluscs are most thriving. Stratified beds of limestone, the shell-banks of bygone ages, are found to have this structure when examined in quarry-sections, their form being that of a greatly flattened plano-convex or double-convex lens, several such banks lying on or dovetailing into one another.

Sometimes a flow of mud or sand will be brought across the shell-bank, and will check its further growth; the bank may be temporarily killed. Then it again begins to grow, the materials now piled on the original bed helping to flatten it down and to give it regularity as a limestone

[1] See J. Murray and R. Irvine, "Coral-Reefs and other Carbonate of Lime Formations in Modern Seas," *Nature*, vol. xlii (1890), p. 165; and Jukes-Browne, "Handbook of Physical Geology," 2nd edit., p. 274.

stratum. Thus alternations of limestone with other rocks may occur at some points, and continuous beds of limestone, stratified by sea-action, at others.

In some climates coral-animals[1] form, by their closely grown or branching skeletons, limestone **coral-reefs** of great extent. Certain seaweeds that strengthen themselves with calcium carbonate also contribute largely to these massive structures. Lumps of dead coral, broken off by the surf, are washed down the slopes and spread the reef steadily seaward; and on its edge all manner of molluscan shells become mingled with wave-rolled fragments of coral and of calcareous seaweeds. The reef becomes thus a stratified limestone on its outer margin; and even within it the swaying action of the surf lays out limestone-mud between the branching skeletons of the coral, and thus produces a kind of stratification.[2] Cementing of the whole mass soon goes on, and the calcium carbonate dissolved off one part of the reef becomes deposited as a means of consolidating the loose blocks at another. Here, then, we have an example, from warmer climes, of how limestone may accumulate with considerable rapidity near a shore.

A pleasing instance of the re-deposition of calcium carbonate from solution in sea-water is seen in the formation of **oolitic grains** upon the flanks of coral-reefs in the West Indies. Little rolling bodies, such as grains of sand or shell-fragments, become surrounded by successive coats of aragonite; and spheroidal grains result, perhaps a millimetre or two in diameter, which accumulate to form "oolitic limestones" or "oolites," becoming subsequently cemented together by calcite into a firm mass. It has been stated that in some cases, at any rate, minute algæ aid in the formation of oolitic grains, as they do in that of limestones deposited from hot springs.

The humble foraminifera also form beds of limestone, which spread evenly, and free from foreign matter, over great areas of the ocean. The remains of those species that live near the shore become, as we have seen, mingled with the ordinary sea-sand, and their abundance is therefore liable to be masked. But some of the most important foraminifera

[1] The term "coral-insect" should never be used, the animal being a polype of far lower organisation than an insect.

[2] Von Richthofen, "Ueber Mendola-Dolomit und Schlern-Dolomit," *Zeitschrift d. deutsch. geol. Gesell.*, Bd. xxvi (1874), p. 225.

swim upon the surface of the water, and consequently flourish above any ocean-depth; hence limestones may be formed of their remains alone, out beyond the zone of materials brought in suspension from the land. The famous genus *Globigerina* thus furnishes a white deposit or "*ooze*" over the ocean-floor at depths of about 2000 fathoms, such deposits being mingled with sand-grains and clay-particles as we approach 500 fathoms. At depths of about 3000 fathoms and more, only red clays, derived from waterlogged pumice and from the ash of submarine eruptions, together with remains of those organisms that make their skeletons of silica, are found over the ocean-floor. The molluscs known as pteropods, and great numbers of the foraminifera, swim freely above these abysmal depths; but the sea-water dissolves away the dead shells during their long descent, and the number of fathoms from which a sample of a marine deposit has been procured will give a fair idea of the proportion of calcium carbonate that it has retained.

Shells, then, and the skeletons of marine organisms, may accumulate to form limestone rocks, while here and there beds of siliceous remains give us deposits of a flinty character. The most extensive examples of the latter are the *Diatom-oozes*, formed by the humble plants already referred to, which lie in a zone round the land-deposits of the Antarctic continent.[1] But the rate at which organic agents form rock masses is slow indeed when compared with the rapidity with which inorganic agents, such as currents, may bring together materials in suspension. New land may be built up visibly by the sea, just as surely as old land may at other points be destroyed. Usually the growth of land is connected with the action of rivers also, and is most noticeable in the neighbourhood of some important delta; but the deposits are sifted and arranged in their new positions by the sea, and marine shells become embedded in them. As an instance of this, M. Reclus[2] calls attention to the remarkable increase of Cape Ferret, in the Department of the Gironde, under the joint action of wind and river and sea-tides. From 1768 to 1826 the headland grew 5 kilometres (three miles or so) towards the south, the

[1] See the interesting Chart I, "Deep-Sea Deposits," *Challenger Reports*. It must be remembered that the area occupied by the Diatom-ooze is greatly exaggerated, owing to the map being on Mercator's projection.

[2] "La Terre," 3me édit., tome ii, p. 215.

rate being 20 to 25 centimetres a day. Since then, however, it has been in part destroyed by the sea and reconstructed.

One of the best examples of new land formed on the British coasts is the broad promontory of Dunge Ness in the east of Kent and Sussex. It is curious to ascend the ridge that stretches between Aldington and Hythe, and to look down into the level land of corn below, and to realise that we are standing on a sea-cliff of comparatively recent times. Dunge Ness itself is formed of marine pebbles of flint carried from the west; the shingle is still so loose that no roads can be maintained across it, and the inhabitants of the surrounding villages traverse it on peculiar flat wooden shoes.[1]

The point of the Ness has grown for two hundred years at the rate of 36 feet (11 metres) a year, or 3 cm. a day. The sea seems anciently to have extended up to Newenden, some eight miles from the present coast, and the river-deltas encroached later on the old marine deposits. To take another case, Pevensey, in historic times, has been banked out from the sea by three-quarters of a mile of added land.[2] Mr. Drew, in the memoir quoted, shows how any obstruction that may be run out into the sea will cause an accumulation of the pebbles, which travel up the bay past Dymchurch from the south and west. The grand line of pebbles that forms the Chesil Bank, connecting Portland and the mainland, may thus have arisen by the occurrence of an obstacle in the form of a clay-bank, which rises there to about the level of low water.[3] At present there is room for a road and a railway along this singular accumulation.

Now let us walk north from our fishing-village, over the low headland on that side, and down upon the flatter coast which catches every wind that blows. Wastes of sand, in which bent-grass grows at intervals, seem here piled upon the pebbly beach. These are the **sand-dunes**, which form such important barriers to many exposed portions of the coast.

When we get among them, we walk with difficulty across the tumbled hollows; and any eddy of the wind drives the

[1] F. Drew, "Geology of Country between Folkestone and Rye," *Memoirs Geol. Surv. Gt. Britain*, 1864, p. 18. 'On Romney Marsh,' see G. Dowker, *Proc. Geol. Assoc.*, vol. xv. (1899), p. 211.

[2] Wm. Topley, "Geology of the Weald," p. 313.

[3] T. Codrington, *Geol. Mag.*, 1870, p. 23. Mr. Cornish has discussed the effects of meeting currents in promoting deposition in this and other cases (*Nature*, vol. lviii. p. 42).

sand sharply in our faces. The curious long curves and semi-circular excavations in these dunes remind us of pictures of the African deserts. These heaps, forming actual hills in some parts, are being reshaped and quarried into by the swirls of the sea-wind. As a matter of fact, the wind has piled them up in the first instance. They are formed of the lighter material, the sand, which could be caught up and carried from the beach by the air-currents; and to this day they are shifting and uncertain. Any little bank or line of obstacles causes a return gust as the wind strikes it, and a deposition of the sand takes place, parallel to and at a little distance from the front of the obstacle. The ridge so formed is added to almost daily on the seaward side, and parts of it are carried away, but more slowly, on the landward face. It becomes damp and compacted with the rain, and then quickly dry again, giving vegetation but little chance upon it; and the bent-grass that somehow manages to exist only helps further sand to accumulate. We seldom see the base of the sharp green lances, as they struggle bravely against the drifts deposited between them.

Sand-dunes have an unpleasant habit of encroaching upon the land, especially in regions of permanent winds from seaward. The unhappy cultivators of the fields in vain build walls and fences to check the advance. The wind, breaking on the wall, forms eddies, indeed, which drive back the slowly moving sand-waves; but the crest of the dune is continually being carried over the wall, and a copious sloping deposit is produced upon the farther side.

Very often long promontories and hooks of wind-borne sand grow out across sea-inlets, as occurs at Portrane in County Dublin. The foundation is an ordinary sand-bar, where the meeting of waves and rivers causes a deposition of the material carried by both. The wind lays hold of this sand as it dries between the tides, and piles it up into irregular heaps. These in time grow larger, as additional sand is brought daily to the mass, and a hummocky unstable ridge results, perhaps forty or fifty feet above the sea, in the place of the wide flat sand-bank.

Land-snails abound in most of these sand-dunes; we can hardly walk without crushing them. Here and there, where a farmer has required sand for his buildings, a cutting has been made into the dune; and we find that some of the

lower layers are cemented into a friable kind of sandstone. The tiny shell-fragments from the beach, together with the broken snail-shells, have supplied the rain with calcium carbonate, and this has been deposited between the grains during the times of drying. Thus true sandstone may be constructed above water by atmospheric action only.

It is a strange landscape, as we sit among these sand-hills, with their yellow slopes gleaming all along the northern bay, and the blue water stretching from them almost without a wave into the Channel. On the low land behind them the fields are all scattered over with the sand; stronger air-currents might convert the whole region into a desert, only suitable to the rabbits which run in and out here beneath our feet. Away at one angle of the bay a low pebbly cliff catches our eye, higher than the beach-terraces that are piled up during exceptional storms. It is clearly something different from the sand-dunes, which at that point have died away; the sea evidently cuts into that corner at times, and no light sand is allowed to accumulate. Our last studies on this coast-line may conveniently be carried on out there.

We have now seen how the shore is a thing of no fixed importance; how, if you make a map on a large enough scale, you may find your work out of date from year to year. The sea seems to determine the shore-line, cutting away here, and depositing there; and even our huge promontory, with its rampart 700 feet in height, seems destined to go down before it, and to be levelled to a pebbly waste. That small cliff over yonder, with the round stones sticking out of it, will, however, tell us that the solid land may in turn push back the sea.

When we come up to it, it does not seem much to look at; it is not very different from the storm-terraces of the beach below. But its top rises far above the level of any modern tides or tempest-driven rollers, and evidently forms a firm continuous plateau for some distance inland. The sea, as we saw, is cutting it away at this point, and making a low cliff which extends north as far as we can see. This bed of old pebbles evidently runs for some miles up the coast.

Our first idea is that it is an alluvial deposit, formed by the numerous streams which run down from the distant hills. But a layer of white crumbling matter attracts us—these are surely the broken edges of shells embedded among the

gravels. (Compare Plate X.) We begin to dig in various portions of the cliff; and soon we may disentomb a whole cluster of periwinkles, with flakes of cockle-shells, and oysters, and a scallop here and there, such as we may find below us on the existing beach.

These shells have, however, lost their colour, and usually their outermost layers; they are in part decomposed, and are not exactly of a modern aspect. Yet we find the same species as still inhabit the Channel, though some of them may now occur farther north or farther south of our particular stretch of country. We may even turn up these shell-fragments on the surface of the fields inland, where the level area ends against the hills, and where we may be fifty feet above high-water mark. Clearly we have here an old beach, a marine deposit, which the sea no longer covers.

The sea, then, has shrunk away? That is possible, but it is not the simplest explanation. The sea is certainly held up against the edges of the land by the attraction of those masses which stand above its surface, *e.g.*, the great mountain-ranges along the coast, and, indeed, any prominent headland. Thus the mean sea-level is higher on any ordinary shore than it would be if the land were perfectly level with high-water mark. The sea, then, must shrink away, and the mean sea-level will be lowered, if denudation reduces the level of these attracting masses; and we have seen that this reduction is steadily going on along our coast.

But this will not be sufficient to account for what has here occurred. If we follow out our old sea-terrace, we shall find irregularities in its level; at one point its top is fifty feet above the sea, but north and south of this it draws near to the sea-level in a distance of seven or eight miles. Moreover, we may be fortunate enough to find that its seemingly level surface is in places sloped down as it stretches inland—the terrace has received a gentle tilt in that direction. When we have studied the older stratified rocks in detail, such evidence will seem to us quite natural. We shall then be quite ready to conclude that the land has been lifted, and irregularly lifted, above the sea.

Such elevated marine accumulations are called **raised beaches**; but we restrict this name to those in which the shells are of modern character and are mostly living in adjacent seas. When we find human remains or instruments

lying among the shells in such a beach, we conclude that the elevation took place after man had appeared upon the earth; and there is no reason to suppose that such movements of the coast have come to an end at the present day. In Sicily beds of very modern marine shells are found 2700 feet above the sea;[1] and in California recent shore-terraces, with the pebbles bored into by marine molluscs, occur at a height of 1240 feet.[2] Some of the occurrences of marine shells of living species at high altitudes in our own islands have been the subject of much controversy; but, in the face of what we know to have gone on in other countries, it is not in any way improbable that the shores of the Irish Channel, for example, have been elevated some 1500 feet in recent times. The earth's crust heaves and moves beneath us in a series of slow but enormous waves. Standing against our raised beach, we can see how it defies, as it were, the destructive forces of the sea. Here, at any rate, new land has been made by a power which hitherto we had no thought of; and later, when we stand among the twisted strata of the Central Alps, we shall remember the evidence of modern elevation afforded by our pebbly coast.[3]

It is reasonable, however, to consider the contrary action —the land may in some areas be on the wrong slope of an earth-wave, and may be thrust down beneath the ocean. The western districts of the British Isles furnish us with interesting evidence that such has actually been the case. The maps of an ordinary atlas show how deeply indented the west coasts of Ireland and Scotland have become; there is a general absence of wide and sweeping bays, such as we associate with sea-action, and in their place we have **fjords**, long winding inlets, penetrating perhaps fifteen or twenty miles into the land. In Norway this feature is developed on a far more striking scale, as any one who has painfully drawn the outline of the coast in his school-days knows full

[1] See De Lapparent, "Traité de Geologie," 3me édit., p. 1383.

[2] A. C. Lawson, "Post-Pliocene Diastrophism of Southern California," *Bull. Depart. of Geology, Univ. of California*, vol. i, p. 127.

[3] A fine example of modern earth-movement, this time in connexion with an earthquake, was afforded in 1891 at Neo, in Japan. A line of fracture occurred 112 kilometres (67½ miles) in length, horizontal and vertical movement taking place along it. In places the ground on one side was raised 20 feet, and the movement affected the hard underlying rocks as well as the alluvium of the surface (Milne, Burton, and Ogawa, "The Great Earthquake in Japan, 1891," plate xx; and B. Kotô in *Geol. Mag.*, 1894, p. 191).

well. But the Scotch examples of Loch Fyne, Loch Long, and the smaller but gloomier Loch Hourn, are admirable for our present purpose.

The walls of a fjord come down steeply to the water, and are continued similarly below. The narrow inlet, with its great depth of water, resembles a flooded ravine among the mountains. Often the mouth is shallower than some portion farther inland, the great Hardanger Fjord of Norway being about 190 fathoms deep at its entry and 440 fathoms in certain spots within; and the depth inside is not related to the depth of the outer sea. Loch Etive, one of the grandest of the British fjords, has an outlet not 3 fathoms deep, set with rocky islets; but soundings give 76 fathoms off Port an Dòbhrain, which is a good twelve miles up the inlet. Clearly hollows such as these cannot result from the battery of the waves.

Sitting on the heathery brae-side above Loch Hourn, and looking up to the rain-swept mountains of Glen Quoich, we see the fjord winding like a sheet of silver between the great masses of the hills. The wild flowers and ferns climb along the banks and touch the water's edge; there is all the tranquillity of a lake, and only in the seaweeds do we catch some suggestion of the sea. At the head of Loch Duich, again, in the purple highland of Kintail, the alluvial floors of Glen Shiel and Glen Lichd come down into the two arms of the water, and the sea-inlet is seen to be perfectly continuous with these valleys. In fact, fjords are nothing else than valleys lowered beneath the sea; the rivers carved them out, and the sea was let slowly into them. Sometimes the moraine of an old glacier lay across the mouth and shallowed it; sometimes the bending of the earth was not regular, and the valley-floor was actually lowered to a greater depth than the sea-floor outside. On the flanks of many fjords, raised beaches can be seen, showing that a sort of see-saw movement has taken place, now of subsidence, now of elevation. This beautiful feature of a mountainous coast is due, then, to a sinking of the land into the sea; and earth-movements have again been the chief factor in determining the coast-line.

Outside the fjords there are generally numbers of islets, running in lines away to sea. These are the crests of partly submerged ridges, being in many cases merely the continuation of the valley-wall on either hand. Lismore, lying in

the mouth of Loch Linnhe, is a ridge that formerly divided the greater valley from a smaller southern one; the sea has entered both and has overflowed the *col* between them. To the west of the north-east point of Lismore the sea has a depth of 54 fathoms; to the east, on the old *col*, it is only 3 to 6 fathoms, with sand-banks gathered around projecting islets. The mountainous back of Jura is, again, the wall of a great valley, the opposite side of which is still seen in Knapdale and Kintyre; and the island of Arran itself is an outlying block of the western flank of a valley that stretched from Galloway to the south foot of the Grampians near Dalmally. The channel to the west of Arran is a second roughly parallel valley, the *col* which once divided it from Loch Fyne being some 40 fathoms under water; while the main valley to the east of Arran has its floor submerged pretty regularly to 80 or 90 fathoms.

Glaciers filled most of these long hollows and kept them clear from *débris*, gradually shrinking away, as they have done in Norway also. At present the deltas of highland rivers are encroaching on the upper waters of the fjords, while the sea is depositing banks across their narrow mouths. In considering marine soundings, we must remember that the form of the old rocky floor is often hidden by these later accumulations.

The study of fjords will lead us on and on to consider still greater features of the world. All round the British Isles accurate soundings have been made, and we know that we stand upon the edge of a great continental plateau, the western side of which drops steeply into the Atlantic. The line marking a depth of 100 fathoms upon our charts passes from the coast of Norway outside the Shetlands and the Outer Hebrides, runs from 25 to 100 miles distant from the west coast of Ireland, and then curves down to Biarritz and continues on close against the Spanish coast. One hundred miles west of County Mayo, in Ireland, we reach a depth of as much as 1400 fathoms, and 300 miles west of Kerry we find 2700 fathoms, or more than 3 miles. Here, then, we are fairly in the ocean; but the British Isles lie entirely to the east of it, and are in no way surrounded by it.

If we return across Ireland, the channel between Stranraer and Larne has a depression reaching 140 fathoms, and 83 fathoms are found between Dublin and Holyhead. Gene-

rally speaking, the hollow between Ireland and England is only 50 fathoms (300 feet) deep.

The English Channel, again, at Dover reaches 30 fathoms in a few local holes, and is mostly only 20 fathoms deep. The broad North Sea, but for a deep channel close to the Norwegian coast (160 to 300 fathoms), measures rarely as much as 50 fathoms.

So that our islands may be regarded as distinctly European, and an elevation of 600 feet would cause an extension of the continent as a broad north-western promontory, bounded by a reduced Bay of Biscay on the south and the narrow Norwegian channel, above mentioned, on the north-east. The whole of the British Isles, including St. Kilda, would become parts of the mainland by such a movement. A uniform uplift of half this amount, of 50 fathoms or 300 feet, would join Ireland to Wales by a tongue of land between County Wicklow and Merionethshire, would bridge the gap from Donegal to Argyll, and would leave a long salt-lake from off Lough Foyle to the south of Dublin. The English Channel would be obliterated, and one could walk from any point on the east coast of England direct to any point in Denmark or in Holland. One or two little salt-lakes would alone remain of our southern and Eastern English seas.

The similarity of the wild land-animals of the British Isles to those of the Continent shows that a connexion must certainly have existed in comparatively recent times. Moreover, Ireland possesses some twenty-one species of mammals, Britain has forty species, and Germany as many as ninety. Allowing for the fact that certain species may have been killed off by their enemies in the restricted space of an island more easily than on a continent, where they could freely come and go, yet these figures show that Ireland was cut off by subsidence from Britain while the latter was still united to the Continent. Mammalian species continued thus to reach England from the east, and then this area was also separated from the Continent. The westward migration of mammalian forms was thus checked by the Straits of Dover, which since then may have undergone many modifications, both in width and outline.

Numerous traditions of sunken land occur, pointing to a former extension of the British group of islands westward of their present boundaries. The fjords are almost all upon

the Atlantic coast; and the steep little cone of Rockall, some 200 miles west of the Outer Hebrides, and the submerged Porcupine Bank, 150 miles beyond the Galway coast, yet coming within 85 fathoms of the surface, are doubtless relics of broader ancient continents. An island, Hy Brasil, is shown in about the position of the Porcupine Bank on a French map of 1640,[1] and I have found it marked even on a chart showing Nelson's voyages, which was published in 1815. The real date of its disappearance remains uncertain.

FIG. 8.—ROCKALL IN 1897.
(*From a photograph by Mr. C. Green;* by permission of the Council of the Royal Irish Academy.)

Thus, as we walk back to the white houses of the fishing-village, and again look away over the curve of the bay, to the great cliff dominant beyond, we realise more than ever the shifting nature of the line where the land meets the sea. Not only does the water wear back the coast, and thrust itself away at other points by building ramparts of pebbles and sea-sand, but forces more mysterious and far-reaching are at work, elevating the whole border of a continent, or letting the sea into the complexities of its denuded surface. What we call the coast is a line of uncertainty and oscillation; and the rocks which border on it can surpass the oldest fisherman in the harbour, in telling us strange and eventful stories of the sea.

[1] W. Frazer, "On Hy Brasil," *Journ. Roy. Geol. Soc. Ireland*, vol. v., p. 128. As to the traditional "sunken land of Buss," between Greenland and Rockall, see G. C. Wallich, "The North Atlantic Sea-Bed" (1862), pp. 63–69. On Rockall, see report in *Trans. Roy. Irish Acad.*, vol. xxxi. (1897), p. 39.

CHAPTER V

ACROSS THE PLAINS

A FLAT country offers comparatively little attraction in itself, but derives most of its beauty from the expanse of air and sky. Beauty it certainly has, but of a kind so vast and indescribable that one has to live in the midst of it to feel its full meaning and its force. The greatness of the level finally comes home to one, especially if some well-known range of hills looms faintly into sight, forming a mere thin blue band on the farthest rim of the horizon. The landscape, as we move through it, is breathed in as a whole; where the details are all so much alike, they all seem equally insignificant.

The Fenland of eastern England is one of these great expanses, which at first seem almost wearisome, even to the bicyclist who skims so easily across them. From Cambridge northward to the estuary of the Wash, there are forty-five miles of level ground, with thirty or so more if we cross the inlet at Fosdyke and penetrate the heart of Lincolnshire. Between the scattered villages lie areas of black peat, covered with coarse grass and dug into here and there for fuel. The roads are carried along the crests of broad embankments, with dark little drainage-cuts on either side of them, crossed by bridges to the fields. A few trees cluster round the old farm-houses, protecting them from the winds that sweep across the fenland steadily for weeks together, now chill and biting from the eastern sea, now stronger and moister from the west of England and the Atlantic. The sky is usually full of great cumulus-clouds, dark grey below and silvery white above, where the sunlight strikes through them in long shafts across the grey-green plain. A church-tower or a windmill is visible ten miles away, when touched on by these sudden gleams; then it sinks back again into the great gloom of the horizon. Far in the south the hills beyond Cambridge may be visible,

with dark woods and a few yellow fields, shining in a clearer air. There is an aspect of thunder across the fenland all the summer; yet the rainfall is one of the smallest in our islands.

Long lines of pollard-willows follow the courses of the streams. The main rivers have mostly been "corrected," to prevent the flooding of the lowland, and to make them serviceable for boats; and high artificial banks confine them in straight lines across the country. The currents of some of these rivers flow rapidly enough, and all are thick with sand and fine brown mud, which they deposit in long alluvial banks as they enter the North Sea. The changes in the form of the coast, due to this deposition, have been very noticeable around the Wash; but a large part of the material there added appears to be mud swept by marine currents from the south-east promontory of Yorkshire.[1]

The fine sandy mud brought down by the rivers can be easily seen at low tide near their mouths. The Glen and the Welland unite west of Fosdyke, and have constructed a flat of compact material in what was once a broad sea-inlet. In the narrow channel remaining, each rising tide produces a rapid inflow of sea-water, entirely reversing the current of the stream. Much of the suspended matter is thus brought back again from the sea itself, together with fine marine mud or **silt**, and these are spread over the alluvial flat, when the tide is full and overflows it. Between the action of the river and the sea, the land is growing slowly outward into the Wash. In John Cary's map of 1822, prior to the Ordnance Survey, the sea is shown forming an inlet three miles long and a mile wide west of the present mouth of the River Welland. The old Cross Keys Wash, to the east of Holbeach, has similarly disappeared, the estuarine deposit having risen high enough for the sea to be artificially banked out and the whole inlet to be reclaimed.

Numerous lakes or meres formerly existed in the fenland, notably Whittlesey Mere in the county of Huntingdon; these have been drained by their owners, and have ceased to break the monotony of the plain. But traces of many lakes of far older date are found among the deposits of this area, and were no doubt destroyed by slow alluvial infilling.

[1] H. B. Woodward, "Geology of England and Wales," 2nd edition, p. 529.

Thus fresh-water shells are found in some of the fenland sections, between layers of clay and peat; while plant-beds and lignite bands show the former prevalence of an approach to forest vegetation. Stumps of oak, yew, and fir have been found beneath the peat, which seems to have spread over the previously wooded ground when a general lowering of the temperature of the district was in progress. The brown and black product known as **Peat** results from the decay of humble closely growing plants, and notably of certain mosses,[1] which love damp surroundings and a temperate climate inclining towards coldness. The general evidence of the deposits of the East Anglian plain shows that sea-beaches, sands, and gravels extended at first far over the present land. Mr. Skertchly writes[2] that the bay of the Wash "was once coextensive with the Fenland itself, and 1300 square miles have become dry ground within recent geological times, and the process is still going on." The rivers filled up the bay at one end, and forests and peat-bogs spread upon the delta; the sea silted up the outward face, where the incoming tides, laden with suspended matter, met the currents from the land. When the deposits had reached high-water level, vegetation sprang up, as it does now, on these marine banks, and not only compacted them, but caused further deposition as every spring-tide overflowed them. In places the sea may have again gained upon the land, through local subsidence of the soft and yielding masses in the estuary; the marine sands and ancient silts, found in drainage-cuts and borings, prove their origin by containing such shells as the common cockle and the periwinkle. Thus our East Anglian plain must be regarded as a complex delta, produced by numerous rivers flowing mainly from the south-west; the sea has assisted in its own defeat, and the land is still growing in a north-easterly direction. Those portions of the alluvial area which are of a sandy or gravely character have long been available for habitation; the peat has already ceased to spread, under the influence of the return of a milder climate and of active drainage-operations; and the seaward front of the delta has been steadily reclaimed by artificial banks erected from the

[1] *Hypnum fluitans*, not *Sphagnum*, is the common species in the Fenland peat (Miller and Skertchly, "The Fenland," p. 555).

[2] Miller and Skertchly, *Ibid.*, p. 224.

times of the Romans to our own. But the plain would have gone on extending, only more slowly, without human intervention.

Thus even this placid country, the old Bedford Level, the Isle of Ely, is, with its many water-ways, in a state of uncertainty and unrest; parts of it are scoured out by the streams as they come in haste out of the hills; and the material, with that brought from longer distances, is deposited again elsewhere along the continually changing coast-line. Our enquiry into the Fenland shows that we are merely dealing on a large scale with the features shown clearly to us in the estuary at our little fishing-village (p. 90), combined with those seen in the broader portions of the river-valley in Tyrol.

This strangely impressive plain of England gives us all the broad effects of Holland, without the trouble of crossing the North Sea. Holland is a country formed out of the delta of the Rhine, and some of the materials beneath its towns may have once formed part of the Alpine ridges 800 miles away. The coast is constantly in a fluctuating state, and large areas have sunk nearer to or even below sea-level in historic times. The drying and compacting of the deposits, assisted by artificial drainage, has caused some part of this subsidence; there is probably also an oozing and a flowing out seaward of the lower beds of sand, which thus produces a sinking of those which have been in later years piled on them.[1]

Sedgemoor, in northern Somerset, supplies to dwellers in the west of England an admirable picture of an estuarine plain. An old narrow promontory, with a road carried along the summit, divides it from the alluvium of the River Brue, which fills a valley reaching nearly to Cheddar. On crossing the back of the Mendips and looking down on Wells, we see this plain of the Brue stretching away to our right, with the island of Brent Knoll standing in it, and the steep cone of Glastonbury Tor rising like a volcano near its eastern margin. If we push on to the south, and cross the promontory above the quarrying-village of Street, we see the second infilled estuary, with the River Parret and its tributaries winding among a number of artificial drainage-ways. Here also there are small hills rising like islands from the plain, and

[1] Suess, "Antlitz der Erde," Band ii, p. 531, &c.

the villages, Weston Zoyland and the rest, are quaintly perched upon them. One historic spot, a steep cone utilised as a fortress in ancient days, still bears a suggestive name, the Isle of Athelney.[1]

These rivers, descending from the southern termination of the Cotteswolds, have, in fact, choked an old sea-inlet, and have piled their alluvium, layer by layer, until it has almost swallowed up the islands. On digging through the peat round these projecting masses, beaches of marine sand are found; and the shells in them are those of common living species. The waters of the Bristol Channel have only been driven out during the last two thousand years, or since the Romans came into the country.

Let us now proceed to cross more spacious plains; they also can tell us their own history.

In the north of Italy a great level surface stretches for 300 miles, from the Alps of Piedmont beyond Turin to the mouths of the Po near Venice. It is continued north-eastward for another eighty miles to Udine and the Austrian frontier; and here, in a more open and uncultivated country, we may study its details most conveniently. Away west, by Milan and Chivasso and Turin, the earliest tributaries of the Po come down from the St. Gotthard, Mont Blanc, and Monte Viso, and suffice to flood the whole level country during a rainy spring or autumn. Up here above Venice we have an independent set of streams performing the same actions, and this north-eastern prolongation will serve as a model of the whole Italian plain.

We have already mentioned the Valle del Ferro (p. 65) in the Venetian Alps, with its cataract of a river, its vertical rock-walls, and its sudden windings which seem from point to point to close the gorge. When we emerge from it at the hamlet of Resiutta, we see the pebbly banks stretching out into a wider valley—deposition of the suspended matter has already commenced. Soon the Fella, which is cutting the ravine, is joined by the Tagliamento from the west, and the two rivers meet in a barren wilderness of stones. Alluvial islands begin to appear among these broader waters; but the torrents in flood-time still carve their way from

[1] For a general account of this district, see H. B. Woodward, "Geology of East Somerset and the Bristol Coalfields," *Memoirs Geol. Surv.* (1876), p. 145. Details of changes at the mouth of the Parret are given *ibid.* p. 159.

side to side of the valley, and are continually altering the features of its floor. Here on our left a side-stream comes down from the Julian Alps; it is so feeble in summer as to be hardly visible; much of it trickles away beneath the banks of stones. But it has brought down, and still is bringing down in rainy seasons, a vast mass of pebbles, which it spreads out in a huge fan. The whole lower slope of the mountain is covered with this deposit, and two or three villages find room for themselves and their vine-terraces and their maize-fields along its lower margin. The shifting and steeper part of the detrital cone has to be abandoned to the caprices of the stream; and up above, at the mouth of the lateral ravine, a red tower, with fantastic battlements, holds the narrow passage through the mountains.

It is a landscape of sudden contrasts, and the alluvial fans, here broader and more nearly horizontal in their bedding than any we have seen in higher regions, are clearly swallowing up the older features of the range, and are producing a uniformity of slope and surface.

The ridges amongst which we are still travelling, forming the outlying parallels of the central mountain-range, have been expressively styled **foot-hills**; and they are literally being buried in the mass of detritus provided by the denudation of high altitudes. By a fairly abrupt transition, we pass from the foot-hills to the plain.

On all sides of us now the level landscape stretches, with a cloudless sky above and a still hot air below. In half-an-hour or so we have forgotten the nearness of the Alps; but we are still some 300 feet above the sea, and the rivers have an active flow. Along their banks we can perhaps read the story of the plain.

Before we cross one of these rivers, the white villages, and the maize-fields, and all the life of harvesters, and brightly dressed women spinning as they walk, and sleek brown oxen drawing low-wheeled carts, vanish utterly away. Rough vegetation, such as bounded the alluvium in Tyrol, prevails for a mile or two across irregular pebbly banks and islets; the roads and railways are carried on viaducts of fifty or sixty arches across streams of the most insignificant character; and, finally, we come to the main river, and then have to repeat the passage of a wilderness upon the other side.

East of the old walled town of Udine, which is built upon a tempting hill amid all this flatness, the Torre and its tributaries come down through such an array of stones that the course of these rivers cannot be set down upon a map—only the broad pebbly banks can be indicated, stretching southward towards the sea. West, again, of the wandering reaches of the Tagliamento, there are similar wastes in which the Cellina and Meduna are literally lost over courses of seven and ten miles respectively, their waters reappearing as recognisable rivers near Pordenone. The Tagliamento, moreover, has lifted itself in places on its own alluvial deposits, until it flows on a broad ridge thirty feet above the ordinary level of the plain (compare p. 69). Farther west still, the magnificent Piave, which runs at San Stefano and Auronzo through one of the grandest ravines in Europe, degenerates into a vagrant group of streams, expanded and divided over a breadth of two and a half miles. If we follow all these rivers down across the level to the Adriatic, we find them terminating in marshy deltas, enclosing backwaters and salt lagoons. On an exaggerated scale, it is the same type of landscape that we have already visited (p. 88) at the Brenta mouth near Venice.

Our studies of the junction of side-streams and main streams in the mountains now come back to us, with a far wider meaning than we could have guessed as we wandered down our upland valley. The whole plain results from the uniting and overlapping of exceedingly flat cones of detritus, which become less clearly bounded, more unstable at their edges, as they leave the limits of the hills. The beautiful steep-sided cones of upper regions, at the foot of gaps in vertical rock-walls, become caricatured, as it were, by the broad triangular areas of pebbles lying on the gentle slopes of the foot-hills. Two or three of these expanded cones meet along the lower parts of their lateral edges, and overlap on one another, according as one or other grows more rapidly. Their front margins push forward regularly into the open valley, or into the waters of some lake, which is thenceforth doomed. Here we have a picture in little of the growth of the Italian plain, formed by cone uniting with cone, delta with delta, all spreading outward into the continental valley of the Adriatic.

On the north side of the Alps, this enormous extension

of detrital banks is almost equally apparent. Much of the original deposition, on either flank of the chain, is no doubt attributable to the glaciers, which at one time formed their terminal moraines much farther north and south than at the present day.[1] But the plains, as we know them, are the outcome of the distributing action of mountain-rivers, working their will upon the old moraines, and also continually adding new fluviatile material.

The area covered by detritus on the north stretches from the Lake of Constanz to Salzburg, and northward nearly to Passau, and is bounded by the steep banks on the farther side of the Danube as we return west by Regensburg and Tuttlingen. Ridges and valleys have been carved out in this region, but here and there it preserves the character of a plain. The period of extensive deposition is past, and the Alpine streams now cut down, for the most part, through the alluvial pebble-beds, and expose far older layers below—layers that were formed prior to the Alps themselves.

As we climb out of the Inn valley near Innsbruck and cross over into Bavaria, we find ourselves on a plateau sloping gently northwards, with numerous streams running towards the Danube, which lies some ninety miles away. The forests soon give place to a more open country, which still falls regularly towards Munich. We can look over this gentle slope uninterruptedly into far blue distance, each village, with its church-tower surmounted by a bulb, standing out conspicuously along the pebbly road. It is a striking contrast after the dense fir-woods that we have just quitted, in which, perhaps, rain was falling and mountain-clouds were wandering; and the farm-lands, catching the sunlight, with little cottages, and sheltering copses, and long green hedge-rows, remind one of rural England, and are none the less delightful. In the great plain before us, everything is covered deep in drifted pebbles; the outermost ridges of the foot-hills have been worn down and buried, and we descend on Munich over the surface of a vast alluvial cone.

The Isar is at this point the most prominent river; but no less than twenty-two respectable streams, all running north or north-east, conspire, with their tributaries, to shift

[1] See Penck, Brückner, and Du Pasquier, "Système glaciaire des Alpes," *Bull. Soc. Sci. nat. de Neuchâtel*, tome xxii.

the pebbles of the plain, to sort them out and rearrange them, in the area between Hohenzollern and Upper Austria. The flow of the Isar is in itself surprising. If we approach Munich from the Danube, we climb up and down over small hills hidden in alluvium, and come at Freising upon the broadest area of the valley. The road ahead seems absolutely level, and right and left for some six miles no semblance of a hill is to be seen. But if we get across by the rickety little foot-bridges, over all the side-streams and back-waters, to the Isar itself, we find a cold green flood rushing between its pebbly banks, swirling round every obstacle in genuine waves, and looking like a mountain-torrent that has somehow got into the wrong surroundings. The peasants have built walls of masonry to prevent its encroaching on the fields, and an area more than a mile wide is often abandoned to it as a playground. The fall is still about ten feet in a mile, and the surface of the plain, which was formed by the union of the river-cones in ancient times, is here becoming cut into by a shallow valley, in which lakes and alluvial flats have no doubt again and again arisen.

Far in the north, the Danube runs under a band of steeply descending hills, and makes a great curve from Ulm to Regensburg, and then down again to Passau. The edge of the plain here coincides with a great line of fracture and movement in the earth's crust,[1] and the river is thus brought against a wall of hard old rocks, such as the Bavarian Forest ridges, which lie on the up-side of this line of movement. The floor of solid rocks underlying the alluvial plain is believed to have sunk, or to be on the down-side of the line. But this would not alone account for the great swing of the Danube towards the north. It looks as if this river had been steadily thrust away in that direction by the encroachment of the alluvial fans from the south, their thin edges pushing forward and spreading the plain-country into the very centre of Bavaria. At present the Danube has been pressed up against the solid northern wall, and can only shift farther by cutting into it at the base. In recent geological times it has been able to carve out a picturesque gorge between white limestone cliffs near Regensburg; and any undermining action now exerted

[1] See Suess, "Antlitz der Erde," Band i, p. 253.

against the northern masses will allow the plain to go on growing.

A river working thus against one side of its valley imitates the horizontal cutting of the sea; it may shift its bed constantly sideways in one direction, and the alluvium brought by itself and by its tributaries will form a flat of steadily increasing dimensions upon the other side. The Danube plain at Straubing is thus quite a one-sided structure; in the north rise the beautiful fir-clad ridges of the Bavarian and Bohemian Forests, the lowest foot-hills of which have been cut into by the river and have formed a band of yellow cliffs. On the south side the country seems absolutely level; the towers of Plattling and Straubing are by far the most interesting objects in the landscape; and the white road, made of the characteristic quartzite pebbles, leads invitingly and easily into Austria under the summer sunlight of the plains.

There is, however, a more imposing spot in Europe from which to study the greatness of an alluvial plain. Let us come away by the railway into Hungary, across the cornland of the Vág, and through the last narrows of the Danube valley to Budapest. The view from the old citadel south of Buda seems to open up all the east of Europe. In the north behind us we have the volcanic hills round Visegrad, the tumbled masses of the mining-country, and the far blue line of the foot-hills of the Karpathians; but south and east stretches the plain of central Hungary, with the grey-green Danube, some 400 yards in width, flowing through it in long sweeping curves. Ever since the river left Vienna, it has tended to divide and to join itself together again, producing enormous elongated islands running in the direction of the stream. Some of these have been carved out of the older alluvium, some have been deposited in the course of the present river; and, were it not for human intervention, floods and redistribution would be the order of the day.

The plain itself is richly fertile, and is now gradually becoming one of the great corn-producing countries of Europe. At sunset a warm pink haze settles across it, and gives even the cultivated portions the aspect of an untouched prairie. Rough brown roads, worn by carts in the surface-soil, connect the hamlets of one-storied houses; and

here and there a little market-town straggles, its streets four times as wide as Piccadilly. In a Hungarian village, there is often room for a water-course on each side and another in the centre of the highway; and the country-roads have no true edges, but wander on and widen out, as if worn by some horde of Asiatic invaders on the march.

On the edges of the plain the ground rises gently towards the great curve of the Karpathians. The corn-fields are found running up as long brown strips over the slopes of rounded ridges, and at last come to an end against the blue-green fir-woods on the mountains. These ridges and hillocks, deeply intersected by little dusty valleys, are the alluvial heaps banked against the solid mountain-side; they are still being added to, but the streams in summer are liable to dwindle entirely away. Great boulders stick out of the banks of yellow earth, as records of former floods and torrent-action; and a change of climate, such as might be produced by an increase in the elevation of the Karpathians, would speedily wash away these accumulated foot-hills and add their materials to the plain. In the great plain itself, stretching for some two hundred miles from side to side, Professor Suess believes that we have an area which has sunk in olden times, leaving the mountains standing about it almost like a ring. In such a gathering-ground, with its narrow outlet on the south-east, the phenomena of the Bavarian plain have naturally been repeated. Whether a lake ever filled the basin is a matter of opinion; for the general flatness of the alluvium might easily be produced by the spreading action of the rivers. Von Richthofen[1] shows us how the fine dry clay of the Hungarian plain, with remains of fresh-water and terrestrial shells, has become carried up the slopes of the mountains by the wind, and has been deposited as a thick coating over the surface. The same observer records sand-dunes,[2] forming characteristic wave-like ridges from north to south across the country; wind-action has doubtless done much in the distribution of the fine materials.

On so incoherent a surface, the rivers have naturally wandered and shifted at their will.[3] The Tisza (the Theiss of the Germans) is a remarkable example; in the central part of its course, near Szolnok, it is working its way west-

[1] "China," Band i, p. 157, &c. [2] *Ibid.*, p. 159.
[3] See Reclus, "Nouv. Géographie universelle," tome iii, p. 313.

ward at the rate of about one foot a year, so that, if a good-sized house were erected on its banks, the river would walk through it in little more than thirty years. It is thus continually cutting into its crumbling western bank, and thrusting back the adjacent towns. The tributaries from the east bring in fans of detritus, which encroach on the main stream, as those from the Alps have encroached upon the upper Danube; and the result is that this part of the river has shifted westward some sixty miles from the fringe of the Transylvanian hills. Farther south, however, its shift is easterly. Trajan and Diocletian erected forts on a plateau on the east bank of the Tisza, close to its junction with the Danube, to prevent the Dacians from crossing; in later times, this plateau became an island, and it is now on the west bank of the river. A similar case of Nature's taking matters into her own hands is recorded by Reclus[1] of a village in the alluvium near Speyr, which stood on the right bank of the Rhine in 1570, and is now, against its will, upon the left.

The Tisza leaves behind it, on one side or the other, dead loops and deserted back-waters, which form curiously curved lakelets until they finally become marshy and dry up. The substances held in solution by the river become concentrated by evaporation of the water, until the residue in the marshes is often salt; and, on the final disappearance of the marsh, these salts become added to the alluvial matter of the plain.

Similar abandoned portions of its course may be seen beside the Danube itself near Mohacs, and they are common along the Drava and the Sava, as they too reach the plain (fig. 10). An amusing result of such shiftings in the soft alluvium of the plains occurred in the summer of 1894 on the borders of Galicia. Since 1892 disputes had disturbed the village of Kudrenice, owing to the movements of the River Zbrucz; and commissioners had finally to be appointed to determine how far Russia and Austria were to be interchanged at the pleasure of this animated frontier-line.

North of Bohemia and the granite-knots of Central Europe, there is a great plain that extends from Holland into Russia.[2] It is, in the Prussian region, covered with mounds and hills of gravel, which sometimes rise 600 feet above the sea; in depressions, or in loops of the low hills, lie abundant

[1] "Nouv. Géographie universelle," tome iii. p. 550.

[2] See Wahnschaffe, "Oberflächengestaltung des norddeutschen Flachlandes," 1901.

lakes, each with its red-brick village on the bank. The only stone is obtained from the boulders in the gravel-pits, and these boulders prove to have come from Scandinavia. In fact, the area was once occupied by huge glaciers, and by streams flowing from their feet and distributing the detritus, until the old rocks became buried some 100 metres or more beneath a great coating of northern "drift." The very gravel ridges, on which windmills are now planted, often represent the matter accumulated by rivers that ran *beneath* the ice, and were left behind when the glaciers at last melted away. The landscapes of this vast infilled basin are fascinating, though monotonous; wind-swept forests, enormous fields where the plough reveals patches of soil of various colours, sinuous lakes, and here and there glimpses of the grey-green Baltic in the north, succeed one another from Hamburg to the bounds of Prussia. At the present day the rivers from the southern highlands are cutting into the drifts and are depositing their own alluvium. Among the more recent accumulations of the plain is the fine material called **Löss.** This is typically a structureless clay, with some sand and carbonate of lime, and contains numerous shells of land-snails, particularly of a species, *Succinea oblonga*, which prefers moist and cool places. It is especially formed where heavy rains in a generally dry district wash down the finer matter from the hillside taluses, and spread it out on the floor of temporary and very shallow lakes.[1] The wind carries away the finest material as these dry up again, and the associated sands may be swept up into dunes. The struggle in such a region between the wind and the irregular clumps of vegetation is well seen in southern Hungary, or along the Polish border.

Von Richthofen urged most forcibly the importance of wind-action in producing löss, in his memorable work on China before referred to.[2] This unstratified yellow calcareous clay, full of the little tubes left by decayed rootlets, light and porous, drying on the surface almost as soon as the rain ceases, has filled up vast depressions in the interior of China and has climbed high upon the flanks of mountain-chains. The waters that soak into it have cut deep vertical clefts, which are often produced by the falling in of the

[1] See I. C. Russell, "Subaërial Deposits," *Geol. Mag.*, 1889, p. 343,

[2] "China," Band i, p. 56, &c.; and "On Loess," *Geol. Mag.*, 1882, p. 293. Also Keyes, *Am. Journ. Sci.*, 4th ser., vol. vi. (1898), p. 299.

material above the courses of underground streams. The landscapes in the plains that are formed by the steady growth of the löss are thus of a most singular character, and the trade-routes of the caravans often lie along the bottoms of cañons, which may be only four to six feet wide. Von Richthofen points out that in rainless deserts fine dust may be formed by the cutting action of blown sand acting on the face of rocks; but this material is carried away by the gusts almost as soon as it is formed. Wind-borne dust, and consequently löss, only accumulates where vegetation already exists; it becomes caught in the twigs and little branchings near the soil, and adds to the mass of the plain. Year by year the vegetation rises to a higher level; the plain is growing under it. Heavy rains would wash off this accumulation; and hence a fairly dry, but not a desert, climate is required for the production of true löss. At present, in China, a period of denudation by rain and rivers has set in, and the löss is being cut into and removed.

The formation of löss depends largely upon the materials supplied to the rain-waters and the steady wind-currents. M. de Lapparent,[1] who believes, in spite of Von Richthofen's arguments, that the löss is the result of the action of heavy rains and of alluvial deposition, shows how the sandy clays of the north of France have become broken up to form löss in the same region. A happy combination of the alluvial theory (p. 133) with that which attributes the distribution to the wind will allow us to perceive that a country where river-muds or loose delta-deposits occur high and dry will be exactly that most suited for the supply of löss-materials, which may then be carried far away, or may be redistributed over the inequalities of the old river-beds near to their place of origin.[2]

We may now profitably glance at the extensive deposits in the north of India,[3] where a combination of such features has actually been at work to produce the plains. These deposits cover 300,000 square miles, with the three great rivers, the Ganges, the Brahmaputra, and the Indus, wander-

[1] "Traité de Géologie," 4me édit., p. 1611.

[2] See the careful discussion by W. F. Hume, *Geol. Mag.*, 1892, p. 549, and 1894, p. 306.

[3] "Manual of the Geology of India; Stratigraphical and Structural," *Geol. Surv. India*, 2nd edit., p. 427, &c.

ing through them and spreading them seaward on both sides of the peninsula. The loops of the Ganges might easily intersect those of the Indus across this huge alluvial level, and so change the drainage of thousands of square miles. The material of the plain is a sandy clay, often cemented in an irregular lumpy manner by carbonate of lime. In a zone about thirty miles wide, extending along the foot of the surrounding hills, true pebbles occur, representing the extreme edge of the ordinary mountain-fans; farther out we find merely sand and clay, the latter becoming very fine in the flatter portions of the plain. Fresh-water shells show that here, as in Europe, we have nothing to do with any incursion of the sea or with the uplifting of a "plain of marine denudation." The present surface is due to river-action, assisted in the less marshy portions by the wind. A well-known boring near Calcutta, finished in 1840, penetrated fresh-water alluvium to a depth of 460 feet below the present mean level of the sea, which shows how depression of the first-formed layers has gone on steadily in the delta.[1] At Lucknow a borehole has found no base to the series of river-deposits even at 1000 feet below the sea-level.

At present the rivers seem less burdened with suspended matter than of old, and run in broad valleys excavated in the earlier alluvial flat. It is probable that, as the deltas become steadily silted up, and as their surfaces become raised by the additions made in times of flood, the flow of the rivers will be checked in their central portions, and deposition will take place in the broad valleys farther and farther up towards their heads. Thus the level of the older plain may eventually be restored.[2]

The geographical changes in a country so constituted may of course be as rapid as in Europe, and are altogether on a bolder scale. It thus appears that the mouths of the Brahmaputra and the Ganges are always struggling with one another; while the Jumna, which now joins the Ganges, flowing through Agra to Allahabad, originally made its way across Bahawalpur to the western side of the peninsula. The dry bed of an old river is traceable along this route for a distance of nearly four hundred miles; and it was probably not abandoned by the Jumna until after the Hindus were in the country.

[1] Compare p. 89.
[2] "Manual Geol. India," 2nd edit., p. 446.

All these great plains that we have been considering contain salts, which sometimes render their surface-soils unfit for vegetation. We have already seen how the drying up of marshes has deposited part of these materials; but in most cases the mere soaking in of rain-water accounts for their presence and accumulation. The rain, with its dissolved gases, attacks the pebbles and the minute mineral grains, and decomposes many of their constituents. The salts carried off in solution sink with the water into the easily permeable alluvium; but there is a constant oozing out and circulation of this underground water, and later rains may even fill up the pores of the whole mass and cause a diffusion of the concentrated solutions that occupy the lowest levels. Thus the salts are in part brought again to the surface, and become deposited there between the grains, or as a white crust, when evaporation has done its work.[1] Von Richthofen regards the tubes left by the rootlets of former vegetation as of importance in allowing such complete penetration of the mass by water. The löss of China is rendered surprisingly fertile by this constant renewal of the salts in the surface-soil, in a happily moderated degree, and the stores accumulated below in bygone times show as yet no signs of exhaustion.

The great deposits of salt in the world had, however, another and a more rapid mode of origin; and this also is connected with the formation of a certain type of plain.

In the States of Nevada and Utah, in North America, and extending into California and Oregon, there is a region known as the Great Basin, the rivers of which either drain into lakes which have no outlets, or disappear in sands before they can reach the ocean. This area includes about 210,000 square miles, and contains a number of plains. Even in its lowlands, it is typically a plateau-country, being usually 5000 feet above the sea.[2] The air of this high inland region contains on an average only half as much moisture as it could absorb before reaching its saturation-point (p. 37); and the rainfall is only ten inches in a year. Towards its south end the Basin sinks in places below sea-level, and layers of salt are here spread over the valley-floors. The Great Basin contains a dozen or more lakes, the largest of which is Great

[1] Von Richthofen, "China," Band i, p. 71.

[2] G. K. Gilbert, "Lake Bonneville," *U. S. Geological Survey, Monographs*, i, p. 6, &c.

Salt Lake, near which the famous city stands; and round this body of water, eighty miles in length, a considerable part of the country bears the character of a genuine plain.

The Great Salt Lake Desert to the west measures about eighty by forty miles, and has a level surface, with but few interruptions. Such mountains and bluffs as rise above it do so steeply, and seem so out of keeping with the general character of the landscape that the older emigrants, passing across in waggons, spoke of them as islands and gave them corresponding names. The plain has shallow depressions here and there, which are converted into lakelets after storms, but which soon dry up again, leaving a surface of compact pale yellow clay,[1] with a deposit of salt around its margins.

The plain as a whole is covered by exceedingly fine mud, impregnated with salts, until we reach its margins, where detrital fans have encroached upon it. The prevailing winds are from the west, and have piled up dunes against the flanks of the hills on the eastern side, illustrating Von Richthofen's theory of the transference and spread of löss.[2]

The Great Salt Lake itself rests as a mere film upon the surface of this plain, being only about fifteen feet deep. Its waters are very bitter in taste, and so saline that the early Mormon settlers used to say that from three barrels of water they could obtain one barrel of salt. In 1850 there were some 22 parts by weight of salts in every 100 parts of water; in 1869 the lake had increased in size, owing to greater supply of fresh water from the surrounding hills, and the salts were only 15 per cent. Results as high as 19.5 per cent. have since been obtained by Dr. J. E. Talmage in 1889. Sodium chloride is the most prominent constituent, both in the waters and in the dried salts, which frequently appear upon the surface of the plains like snow. On the cooling of the lake in winter, crystals of sodium sulphate are thrown down, and may often be gathered from the bottom.[3]

[1] For an important account of these "adobe" deposits, and a comparison with the löss, see I. Russell, "Subaërial Deposits of the Arid Region of North America," *Geol. Mag.*, 1889, pp. 289 and 342.

[2] Hague and Emmons, "Descriptive Geology," *U. S. Geol. Exploration of 40th Parallel*, 1877, p. 466.

[3] For these and other points, consult Gilbert's fine monograph, above cited, which is enriched by a handsome series of illustrations.

This remarkable salinity of Great Salt Lake is paralleled in certain seasons by the smaller Sevier Lake far away to the south, which actually dried up in the autumn of 1879. A salt-layer four or five inches thick resulted, formed of sodium chloride, sodium sulphate, and magnesium sulphate. The irrigation-works carried out in the valley of the Sevier River had in this case diverted the supply of water.

Some twenty-five miles south-west of Salt Lake City, there is curiously a fresh-water lake without an outlet, called Rush Lake, which is believed by Mr. Gilbert to have dried up in recent times, and thus to have deposited all its dissolved material. This layer of salts has then been covered by some stratum of mechanically suspended matter, and the lake has since been filled up again with fresh water from the hills. Utah Lake is fed from the Wahsatch Mountains, and flows out into Great Salt Lake, and is consequently fresh.

How has the Great Salt Lake, however, become so conspicuously salt? We have already hinted that it is subject to changes in volume; in the spring the water rises, owing to the melting of snow upon the mountains, and in summer it falls, owing to the evaporation from the surface. But larger changes are in progress, due to alterations in the local climate; and any slight increase in depth means, in so shallow a depression, the flooding of a vast amount of the plain. Thus in 1850 the lake covered 1750 square miles, and this was increased to 2170 square miles in the course of the next twenty years. At present the area is decreasing, evaporation being in excess of the supply.

In studying such fluctuations, we begin to see how the salt has accumulated in the lake. Surely it must be due to the old outlet having disappeared, and to the fact that evaporation has served in its place to remove the continual additions of river-water. The salts, as in the marshes of the Hungarian plain, have thus been left behind; and, but for occasional rainy seasons in the hills, the salinity would be steadily on the increase.

But, further, if we examine the walls of the mountains beyond the long dreary miles of plain, we find that they are marked by horizontal terraces, and that they have been actually excavated along these levels, cliffs being produced, as if by the waves of ancient seas. Beaches occur, sloping down from these terraces, and sand-banks and bars of

various forms are common (fig. 9). The "islands" of the Great Salt Lake Desert, when examined closely, resemble islands indeed, with similar terraces carved out of them by the waves. The cliffs that are so suggestive on the mountain-flanks rise to a height of 1000 feet south of Salt Lake City, with long sand-spits stretching from under them into the plain. A long series of explorations in this district has proved beyond a doubt that formerly an enormous lake not

FIG. 9.—OLD LAKE-TERRACES OF THE SALT-LAKE AREA OF UTAH — THE GATE OF BEAR RIVER. (From "Lake Bonneville," by G. K. Gilbert; by permission of the Director of the U. S. Geological Survey.)

only occupied the Salt Lake Desert, but ran on southward in broad inlets over the salt-strewn plains and valleys. This lost lake has been called "Lake Bonneville"; it rivalled in area the inland seas of the northern States, being nearly as large as Lake Michigan;[1] for it was 346 miles long, and 130 miles wide, measured from Salt Lake City across the western desert. The waters rose about 900 feet above the present level of the plain.

[1] Gilbert, "Lake Bonneville," p. 105.

The wave-cut terraces on the shores and on the former islets represent successive levels at which the water lay continuously for long periods. The area of sloping beaches from one terrace to another corresponds to a time of fairly rapid decrease or increase in the volume of the lake. It appears that Lake Bonneville had a notch in its northern walls, at the head of the Cache Valley, which was banked up by alluvium; and, when the waters were once high enough to flow over this pass, the soft barrier rapidly gave way, and a flood poured out towards the Snake River, which rapidly reduced the level of the lake. The torrent in the outlet finally cut its way down to the underlying limestone rock, and here continued to flow over without materially deepening its bed; a second zone of terraces, 375 feet below those formed at the highest level of Lake Bonneville, marks the shore-line of this later resting-stage of the lake. We even know that the area of the lake at this period remained fixed for a longer time than when it was at its highest level, since the lower series of wave-cut terraces is far broader than the upper, and the banks of accumulated detritus are far more massive.[1]

But finally the lake began to shrink away, until the basin became a closed one, the water no longer reaching to the outlet. As the water was removed by evaporation, the surface steadily sank, and the alluvial cones from the hillside-streams grew downwards and outwards over the old terraces and slopes. Whether the huge Lake Bonneville ever actually dried up is a matter that cannot be determined; but probably the Great Salt Lake, Utah Lake, and Sevier Lake are the last relics of its grandeur. The salt-marshes that are formed everywhere in the depressions after rain show how the floor retains much of the matter once held in solution by Lake Bonneville, while Great Salt Lake remains as its concentrated and still liquid representative. The river-waters still flowing into the old basin of Lake Bonneville contain about .025 per cent. of material in solution, while Great Salt Lake contains, as we have seen, about 760 times as much.

Thus the wonderful level plain, so strikingly contrasted with the terraced mountains and the "islands," represents the **old lake-floor**; it proves to correspond on a large scale

[1] Gilbert, *op. cit.*, p. 127.

to the little grass-grown flat-bottomed basins so often met with in the Alps. When we say that Lake Bonneville rose 900 feet above Great Salt Lake, we only gain an imperfect idea of the true magnitude of its basin. The greater part of its hollow has become filled with sediments, the outermost washings from the surrounding cliffs; these have been spread out in level layers of fine mud and sand over the whole central area, pebble-beaches running out into the deposits from the shores and islands. Mr. Gilbert believes that the lake-alluvium reached a thickness of at least 2000 feet; erosion at the present time cannot carry the material out of the basin, and it is merely raised by the wind into long dunes in drier areas, or flattened down and caked together in others by the casual showers of rain. The foundation-layers of this great mass of alluvium belong to a period of lake-formation when the boundaries of Lake Bonneville were not yet established; the hollow began to be filled up in far earlier geological times, and the total deposit may reach a depth of several miles.[1]

Thus plains, graduating into salt-deserts, may arise by the total abolition of ancient lakes. At the present time the floor of the Lake of Geneva is extraordinarily and almost mathematically level, after we once get beyond the steep banks formed by the continuation of the alluvial cones beneath the water. This level surface of finely sifted detritus, free from the swirl of currents and from any erosive action, lies at a depth of about 1000 feet (309.5 metres) below the surface.[2] This figure reminds one curiously of the relations formerly existing between the Great Salt Lake Desert and Lake Bonneville.

Mr. I. C. Russell[3] has described another ancient lake in the Great Basin, lying near the north-west frontier of Nevada. "Lake Lahontan" was nearly as long as Lake Bonneville, but contained a great pear-shaped island which largely reduced its area. Seven saline lakes still lie in the floor of it, which are believed to be produced by flooding of the hollows after the complete drying up of Lake Lahontan. One of these, North Carson Lake, twenty miles

[1] Gilbert, *op. cit.*, p. 99.
[2] Forel, "Le Léman," tome i, pp. 51 and 109.
[3] "Geological History of Lake Lahontan," *Third Ann. Report U. S. Geol. Surv.*, 1883, p. 195.

long and twelve miles wide, has been known to disappear by evaporation, leaving for a time "a plain of saline mud" as a continuation of the area of fine clayey sediments which form the Carson Desert. The depressions of this area, like those of Lake Bonneville, are occupied by level deserts, which represent the alluvial infilling of the great lake; and salts are constantly accumulating in crusts upon their surfaces, being brought by circulating waters from the strongly impregnated sediments below. Sodium chloride (common salt) and calcium sulphate (which combines with water and crystallises as Gypsum) are especially prominent constituents of these dried materials. In a closed lake-basin, as Mr. Russell points out,[1] fed by ordinary river-waters, calcium carbonate will be the first material to separate out on the evaporation of the lake, since it is the most abundant and least soluble salt in the rivers; then calcium sulphate will be deposited, and then, after the loss of almost all the water, sodium chloride, the chlorides of magnesium and calcium following even later still. Both the shores of Lake Bonneville and Lake Lahontan give, in their layers of friable or compacter fresh-water limestone, known as **Tufa**, ample evidence of the deposition of calcium carbonate from solution. Often this deposit acts as a cement to bind the grains together in the sand-banks.

Another feature of lake-deposits is the formation of hydrated iron oxide or **Bog iron ore**. The iron is brought into the water by the rivers, being held in soluble combinations by the acids produced by the decay of land-vegetation. These compounds break up under the oxidising influence of the air, when carried into bogs and marshes, or into the broad and constantly circulating waters of a lake; and an insoluble substance, brown rust, or hydrated iron oxide, is produced. This accumulates at the bottom round water-plants and pebbles and sand-grains, and sometimes even forms little spherical concretions, which become heaped together, making a workable ore of iron. Hence lake-deposits are typically reddened by this coating of iron oxide over the surfaces of their constituents; and nothing is commoner, when we attempt to work out the past history of an area, than to come across beds of rock-salt and gypsum, associated with

[1] *Op. cit.*, p. 229. See also A. J. Jukes-Browne, "Handbook of Physical Geology," 2nd edit., pp. 243, 247.

red clays and sandstones and conglomerates. Fresh-water shells may help us to form a true judgment as to the mode of origin of such strata; but the very absence of evidence of marine life, and the mineral characters of the rocks, will prove that we are examining the floor-deposits of an evaporated lake. Along the railway between Larne and Belfast, such reddened strata, with gleaming interlacing bands of gypsum, form an admirably clear example; and great beds of rock-salt are found in the immediate neighbourhood in borings in the same series of strata.

Thus the study of modern plains has led us to the consideration of lake-deposits, with which they are so often associated. In conclusion, let us glance at one or two areas of evaporation nearer home.

The Dead Sea, in Palestine, is almost too familiar an example. The region in which it lies is nearly rainless, and it has no outlet, although the Jordan is steadily flowing into it. The surface of the lake lies 1292 feet below that of the Mediterranean Sea, and the water is in places 1200 feet deep. A large body of water has, however, been removed by evaporation, the alluvial terraces in the Jordan depression occurring as high as 1400 feet above the present surface. The molluscan shells (such as *Melania tuberculata* and *Melanopsis Saulcyi*) occurring in these old deposits show that the lake was originally fresh.[1] When it had shrunk to 600 feet above its present level, it deposited, as at Jebel Usdum, salt and gypsum in the clays and sands. New materials were brought into it; it may have spread and again contracted; and similar deposits occur on the promontory of El Lisan, 300 feet above the present surface. The lake as we now know it is devoid of animal life, except for some small fishes near the entry of springs at its southern end. Cubes of rock-salt and plates of gypsum are being deposited upon its floor, where the water is more saline than in the upper layers. Captain Lynch,[2] of the American Survey of this region, obtained water from a depth of 1110 feet, which had a specific gravity of 1.227, and which contained salts equal to more than a quarter of its weight. The analysis is instructive, showing, like all those

[1] *Survey of Western Palestine, Palestine Exploration Fund;* "Geology," by E. Hull, p. 80.

[2] Quoted by Bischof, "Chemische und phys. Geologie," 2nd edit., Band i, p. 313.

of the waters of this particular lake, a remarkable preponderance of magnesium chloride. Perhaps part of the sodium chloride has already been abstracted by the commencement of the process of deposition (see above, p. 142). The analysis showed:—

Magnesium chloride	14.590
Sodium „	7.855
Calcium „	3.108
Potassium „	0.659
Calcium sulphate	0.070
Potassium bromide	0.037
	26.319

But there is every likelihood that the water of the Dead Sea becomes tampered with, as it were, by the volcanic springs which open into it. In any case, it is a very abnormal water, as we at present know it. M. Lartet,[1] a French explorer, showed that the specific gravity at the surface was 1.0216, increasing to 1.2533 at the bottom, with as much as 27.8 per cent. of salts. Should the Dead Sea finally evaporate altogether, a limited alluvial plain would be produced at the bottom, singularly placed some 1500 feet below the level of the Mediterranean.

If we are here dealing, as in Utah, with a lake of fresh water slowly concentrated, in other areas we have similar phenomena produced by the drying up of portions of the sea. The plains around the Caspian were originally the floor of a sea extending northwards and westwards, at a time when probably the Bosporus was not yet opened. The Black Sea and the Sea of Azov then communicated with the Arctic Ocean, by way of the Caspian steppes and the Sea of Aral. Marine shells are found in the plains at present intervening, and the animals still living in the saline Aral and Caspian waters show an original connexion of these inland seas, both with one another and with the Arctic region. Slight earth-movements have raised a barrier which crossed the old line of communication; even now a rise of 84 feet in the waters of the Caspian would connect it with the Sea of Azov; by an increase of 242 feet it would reach the Sea of Aral; and a further rise of 62 feet would cause this great sea to drain out by the Obi route into the Arctic Ocean.[2] But no such results

[1] "Voyage d'exploration à la Mer Morte," tome iii, p. 278.

[2] See W. B. Carpenter, article "Caspian Sea," *Encyclopædia Britannica*, 9th edit., vol. v.

are now obtainable, without a depression of the Aral region, or the elevation of a whole new ridge to prevent the waters draining westward. Mere filling up of the present basin, as above suggested, might serve to connect the Black Sea and the Caspian; but after that, to include the Sea of Aral, we must raise the level of the Mediterranean waters also, and hence of the Atlantic Ocean.

It can be shown that the plains around the Caspian result from the diminution of the waters, for old shore-lines occur some seventy feet above the present surface; and the shrinking of the older lake must have been rapid, seeing how slightly denudation has laid hold of the region between the upper terrace and the present one. The great changes in physical geography which cut up the former north-east sea and drained the Black Sea basin into the Mediterranean may actually have occurred since man appeared upon the earth. The great Danube itself may thus, almost in historic times, have sent its waters to the Arctic Seas.

The present Caspian is, however, not necessarily a relic of the north-east sea. It may have arisen from a refilling of the old marine depression with ordinary river-water. It is certainly for the most part far less salt than ocean-water, and even than the enclosed Black Sea. But much of the salt is being withdrawn by deposition in certain areas of extreme evaporation, such as the highly saline Bay of Karaboghaz; into this a current constantly runs to maintain the level of its surface.

The Desert of the Great Sahara is in parts a plain in which wind-action has full scope. It has often been said that its present surface was an old sea-bottom, like much of the country round the Caspian; but recent enquiries have thrown doubt on this,[1] and the plain as we know it may be ascribed to wind acting in a region practically devoid of rain. Doubtless the old basin, an area of depression, was there ready formed at the time when the climate became dry and when vegetation began to disappear; then the soils that had already accumulated were laid hold of by the prevalent north-east winds, and were carried into the air as clouds of dust. Much of the finer material may have disappeared, having gone to form löss elsewhere; the sandy residue, with numerous coarser and pebbly banks, remains to form the desert

[1] See De Lapparent, "Traité de Géologie," 4me édit., p. 1639.

floor. The sand-grains, rubbing constantly on one another, become cleaned and polished, to a degree unknown among river or sea sands; larger pieces of rock become scored into and pitted by the friction of these particles against them; and the wind also carries the sand in powerful blasts against the barren hills, and sculptures them into slabs and pinnacles and all manner of fantastic forms. The sand lays hold of natural lines of weakness, such as joints or bedding-planes, and excavates the rock along them; hence the horizontal stratification of some desert-cliffs becomes emphasised in a striking manner. The Sahara varies considerably in height above the sea, including several plateaux of 2000 to 5000 feet; some parts are swept bare down to the bed-rock, which becomes polished by the passage of sand over it, while others show saline traces of former lakes. Sand-dunes 300 feet high have been formed in those areas in which the transported material has taken refuge; and smaller conical heaps, prolonged into crescents by the wind-eddies, are a common feature of the landscape. On the east of the Sahara, the sands of the Libyan Desert travel before westerly winds towards Egypt, which they literally invade, burying its tombs and temples. The plain grows steadily in this direction; in fact, we see here the delta of one of the broad currents of the air.

Now we have probably learned enough, in running in fancy over all these regions, to convince us that plains have a genuine interest of their own. We may be living for years in an absolutely level country before it will yield up all its secrets; and then we shall probably find that the enormous landscape, in which the sky plays so large a part, in itself reflects the history of the plain. Width and space, whether of wind or water, are the first necessities. Climates may have changed; the sun may now be obscured by cloud-drifts where once it ruled in splendour; rich grass may have spread across the worn-down and scattered desert-dunes; gleaming patches of salt may alone represent the blue waters of some inland sea; but the sense of space is still with us, and the region is still a playground for every wind that blows. Even the mirage, by which the desert seems converted into a sheet of water, may be a faithful picture of the past; and the turning up of a common cockle-shell under the foot of the traveller may arouse trains of thought that will be a recom-

pense for many weary days. But there—we have wandered far from our own familiar fenland. The moon is rising over the long chalk ranges, and the short grass gleams as if already touched with hoar-frost; behind us the soft sheets of mist are stealing across the hollows of the fen. In an hour or so the express will carry us to London; and there will still be time to catch the boat at Dover.

FIG. 10.—LANDSCAPE IN THE ALLUVIAL PLAIN OF THE SAVA, SELO, CROATIA.

(*Photographed by the Author.*)

CHAPTER VI

DEAD VOLCANOES

OUR course now lies through central France, for we are bound on a perfectly new errand; and the first landscape that we will consider is the view from Thiers, in the Department of the Puy de Dôme.

We arrive at the town from the east through a little granite ravine, where the road and the railway wind along the cliffs, the latter disappearing and reappearing among the rocks in true mountain-fashion. Then suddenly we are close to the roof-tops of the houses, which are piled on the steep descent to the valleys of the Dore and Allier.

Over against us, five-and-twenty miles away, rises the long granite plateau beyond Clermont-Ferrand; and upon this is set the range of hills that we have come thus far to see. The steep-sided round-topped mass, conspicuously higher than the rest, is the famous Puy de Dôme, 1463 metres (4800 feet) above the sea. North and south of it a number of hummocky isolated hills form a broken band on the horizon. The great plateau is about 3000 feet above the sea, and many of the summits rise for another 1000 feet above it.

This distant range is the "Chain of the Puys," or the "Monts Dôme," which have given such geological interest to the old province of Auvergne. The name *puy* is locally applied to any elevated mass short of a true mountain-peak. Even at this distance, the double character of the opposite wall of the valley can be discerned—the ancient plateau, part of the very core of France, and the row of puys placed disconnectedly upon it.

We descend into the wide valley, cross the Dore at the foot of the terraced streets of Thiers, and the Allier also under the cliff of Pont du Château. The roads are now made of the black rock known as basalt, masses of which we shall soon meet with on our way up to the granite

plateau. Two miles on this side of Clermont, we pass an odd flat-topped little cone, quite different from the other surface-features of the valley, and resembling the puys that now draw near above us.[1]

To understand a country such as this, it is well to make a preliminary survey from a height. We shall do well to leave the fine mass of the Puy de Dôme till later, and to go up the winding road to one of the northern hills, the Puy de Pariou. The roadside-cuttings show us compact dark rocks, some of which have little hollows like bubbles in them. Occasionally we see the pale brown granite, which forms the foundation for the hills.

We are now on the bleak and open plateau, with the enormous valley again below us, stretching northward to join the Loire. The ground is covered with heather and dry peaty soil, and beech-woods cluster thickly round the bases of many of the hills. Short wind-swept grass clothes the Pariou, and climbs the steep slopes towards the Puy de Dôme; and loose patches appear on most of these hills, where the rock seems too crumbling to allow the vegetation to lay hold.

The beautiful curving outline of the Puy de Pariou attracts us even at a distance. The slopes lead up to a wide crest, which sinks again slightly in the middle; and on the north an outer rampart, like an artificial earthwork, follows the curve of the hillside. A very little inspection will show us that the whole hill is circular in plan, and that its summit-ridge forms a complete ring.

It is a fairly steep climb after all, for the angle of the slope on the west is as much as 27°,[2] and slips of the loose material seem common. We will examine the porous substance of the mountain later, when we have grasped the general structure. Above one of its broad bare regions, the crest is a little higher than elsewhere, rising some 750 feet above the plateau; when we reach it, we find ourselves on the edge of a great circular depression; the ground, in fact, falls inwards towards the centre of the hill at a

[1] For a detailed description of this region, see G. P. Scrope, "The Geology and Extinct Volcanos of Central France," 2nd edit., 1858, and sections x. (M. Boule), and xiv. (M. Lévy), "Livret-guide des excursions en France," *8me. congrès géol. international* (1900). Also Bonney, *Proc. Geol. Assoc.*, vol. xvii. (1901), p. 191, and *Ibid.*, pp. 269–332.

[2] Measured from a photograph by Mr. G. W. Butler, F.G.S.

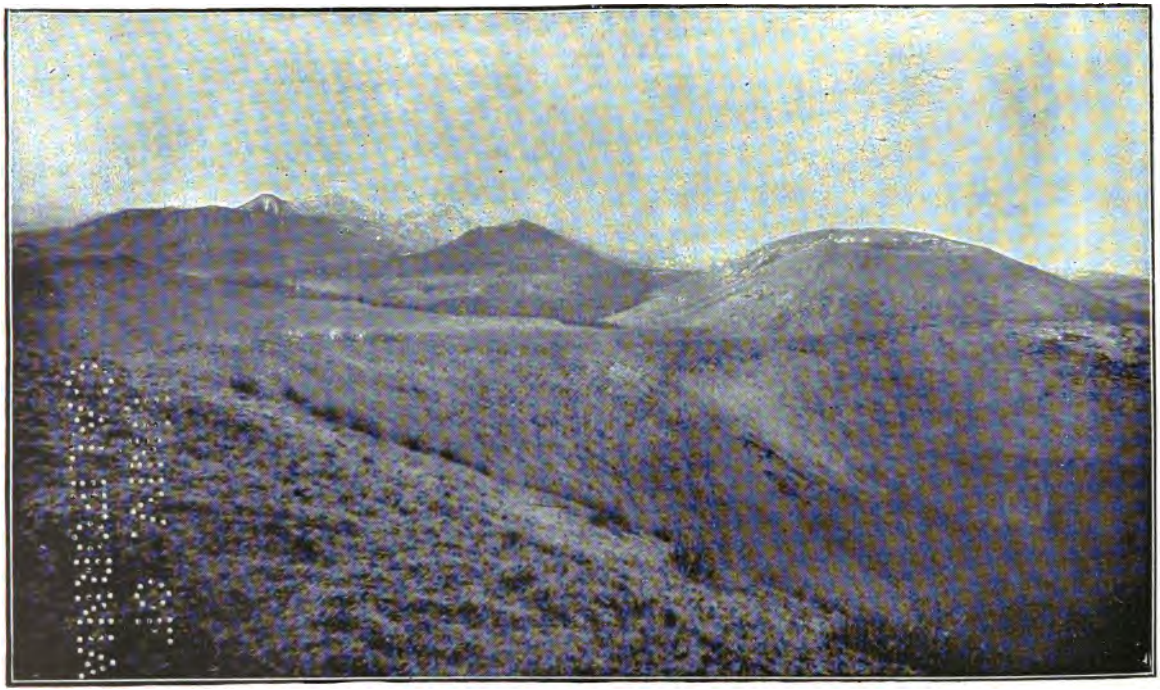
still steeper angle than it does towards the outer plateau (Plate V).

This is altogether unreasonable, and contrary to the custom of ordinary hills. The cup-shaped hollow before us is 300 feet (93 metres) deep, and about three times as much across; and its rim is often only five feet wide, and in places is almost sharp, requiring careful walking as we trace out its circumference, a stroll of more than half-a-mile. From this crest of vantage we look over other lesser puys, and perceive how this circular basin-shaped form is really typical of the district. The Puy des Goules, in particular, quite near us, has a perfect ring-shaped summit, broken only by a little clump of bushes on one side.

Beyond the Puy des Goules is a round-topped pudding-like mass, which we must investigate separately. To its left is a stretch of woodland, and then the Puy de Chaumont rises, with the same fascinating outline, its flanks slightly concave, as is so common in this group of hills. On its left is the steep Puy Chopine, a craggy mass defended by a rampart, like the half of a broad ring, the outer sides of which are seamed with water-courses formed in times of rain. In the far north other ring-shaped mountains rise, and then the plateau drops on that side also into the plain. On our left is the fine cone of the Puy de Côme, higher than the point on which we stand; and a rough broken country descends from it, largely covered with wood, to the western valley of Pontgibaud.

If we now examine the materials that build up the Puy de Pariou, we may gain some clue as to the mode of origin of this extraordinary group of hills. The loose bare portion of the slope is made of little stones full of bubbles, light and cindery, of various shades of grey, all heaped together to build the ring-like ridge. Were we to probe elsewhere into the grassy sides, we should find this same slaggy sort of material; its very looseness, causing the rain to soak into the mass so easily, is said to account for the slight hold that denudation has upon the mountain.

One of the best spots for seeing how the puys are often perfectly fragmental, beneath their covering of grass or trees, is the hollow in the Petit Puy de Dôme to south of us. Here we have cindery masses of all sizes, purple-grey and purple-brown; and some of the larger ones are spherical,



THE CRATER-RIM OF THE PUY DE PARIOU, AUVERGNE.

Beyond, on the right, are the cone and crater of the Puy des Goules.

PLATE V.] [*Photographed by* Dr. TEMPEST-ANDERSON, F.G.S.

with a compacter crust and an interior more full of bubbles. The exposed slope is here so loose that it is very difficult to ascend.

Surely all that we have read about volcanoes will come vividly before us here. A volcano is a place where molten rock, called **lava**, issues from the ground. Explosions occur, and "cinders" and "ashes" are scattered freely round the vent. Occasionally the lava itself flows out as a slowly moving stream, invading the lower slopes of the country. The outbreak or *eruption* commonly occurs from the summit of a mountain, the opening whence the cinders and lava issue being funnel-shaped and styled the **crater.**

The study of volcanoes was not undertaken in detail until nearly the close of the last century; and the relations between the eruptions and the volcanic mountain were at first only dimly realised. There was a natural idea, which is still very common among popular writers and journalists, that flames and smoke were the prominent features of an eruption. As a matter of fact, such flames as occasionally occur result from the ignition of gases in the crater; they are pale, and are invisible at any distance. Smoke, such as occurs during the burning of compounds of carbon, is entirely absent. The white-hot melted rock, thrown up into the air, resembles at night a column of fire; while fine dust is produced, together with dense clouds of steam, the latter being emitted at every throb of the eruption; the mingled matter, floating above the volcano, naturally resembles smoke. An enthusiastic student, indeed, once stated in an examination-paper that "a volcano consists of flames of smoke," which was going even farther into reckless error than the ordinary writer in the newspapers.

Perhaps the most surprising fact is that the steam is the motive-power of the eruption. Water permeates all rocks down to great depths in the earth's crust. Now it is perfectly certain that the interior of the earth is hot, though we are not prepared to say how far any part of it is actually molten. Miners, and engineers engaged in tunneling, frequently suffer from the rise in temperature, which careful experiments show us amounts to 1° F. for every 50 or 60 feet of descent, or 1° C. for every 100 feet or thereabouts. We do not know from these experiments, made as they are in one mile out of the four thousand between us and the

centre of the earth, whether this rate of increase of temperature is constant; but it is clear that very high temperatures do occur within a short distance of the surface. Quartz melts at 1430° C.,[1] which might be reached in twenty-eight miles; while a large number of rock-forming silicates could be melted at a considerably less depth. Dr. Joly shows us, indeed, that "a preponderating number of mineral bodies possess melting-points ranging within the comparatively narrow limits of 900° C. to 1500° C."

But probably the great pressures brought to bear upon minerals at such a depth would raise their melting points, affecting different minerals in different degrees. Certain portions of the crust, however, such as the lines of junction of continents and oceans, are in a state of movement and unrest, whereby pressure is increased at some points and relieved at others. Any important relief from pressure, such as would be afforded by the lifting of the outer layers of the crust to form a shallow dome, will allow some of the highly heated rocks below to pass into the liquid state.

Now, water has already permeated these rocks, but has similarly been subjected to pressure, whereby it has been prevented from expanding into steam. When any relief from this high pressure occurs, the presence of water assists in rendering the rock fluid; and the water, moreover, begins to expand on its own account and to bear the whole mass up into any fissure that may be at hand. Should any portion of such a fissure reach the surface, the molten rock is rapidly lifted to the outer air, the water now expanding into steam. The vapour thus produced may escape with explosive violence, blowing the lava into fragments and sending them spinning hundreds of feet into the air. Such flecks of melted rock, fluid at the moment of their ejection, become spherical or elongated as they move swiftly upwards; a compact and often glassy crust forms on their outer surface, and the steam still imprisoned by this rapid consolidation renders them full of vesicles within. Such masses, perhaps two, ten, or twenty feet in diameter, are called **volcanic bombs.**

More often, the melted rock, the lava, rises in the vent provided for it, and its upper surface cools and becomes

[1] *Proc. Roy. Irish Acad.*, 3rd ser., vol. ii. p. 39. Dr. Joly has since shown that prolonged heating may allow a mineral to become plastic at a temperature below its ordinary melting point.

solid, although remaining still red-hot. The product is like a scum, which heaves, and sways, and becomes broken up, on the surface of the liquid mass below. It is full of cavities where the steam has blown its way out of the viscid material, or has raised it into bubbles while struggling to escape; and every now and then this crust of solid lava becomes blown suddenly into the air by the steam which has been imprisoned below it in the vent. Thus red-hot stones come flying out, accompanied by a great burst of steam; these stones fall around the mouth of the volcano, and are called **scoriæ**, from an Italian word meaning a frothy scum. When cold, they may be picked up, and are seen to be irregularly shaped and full of bubbles; and hence any vesicular rock is said to be *scoriaceous*. The scoriæ seldom reach us in exactly the form in which they were blown off from the lava-crust; they come out in such abundance that they strike against one another in the air, producing a strong hurtling sound, and thus they become broken into smaller and smaller fragments. The somewhat coarse deposits formed of scoriæ, usually with finer matter acting as a groundwork and as a cement, are known as **tuffs**, a word coined from the Italian *tufa* or *tufo*.

Pumice, which is so widely used for cleaning purposes, is merely a refined and glassy type of scoria. The molten rock has been expanded by a vast number of steam-vesicles, which have become drawn out into almost tubular forms by the flow of the mass, as it rises and falls in the volcano and during its final ejection. If a piece of pumice is melted again, it shrinks into a black mass like bottle-glass. The white colour of pumice is merely due to the immense proportion of air-spaces that it contains; light cannot pass through it, but becomes reflected again and again; and the fibrous character of the mass gives it the lustre of spun silk. Professor James Dana found that some particles of pumice from the Sandwich Islands consisted of 1 per cent. by volume of glass and 99 per cent. of air-space. A freshly broken surface of pumice, examined with a lens, is an object of great delicacy and beauty.

If two pieces of pumice, however small, are held one in each hand and are rubbed together, a very fine dust arises, which consists of tiny broken shreds of glass. This corresponds to the finer varieties of the material known as **volcanic**

dust or **volcanic ash**, which is produced by the friction of pumice fragments as they strike one another in the air. In all violent eruptions, this most delicate and glassy ash forms a large part of the heavy mammillated cloud that drifts away before the high currents of the atmosphere. A sifting process goes on, the bombs and coarser scoriæ falling close around the vent, and many of them dropping back into it; the finer scoriæ lie somewhat farther away; while the minutely divided ash is carried by the winds to immense distances before it settles. The dust of Krakatoa, in the Straits of Sunda, erupted by the great explosion of August 26th, 1883, travelled thus at least twice round the globe at a rate of seventy-six miles an hour. From their effects in producing a halo of a particular angular diameter round the sun, the particles of volcanic matter were calculated in this instance to be from .003 down to .001 millimetre in diameter.[1]

The illustration here selected (fig. 11) is reduced from one of the beautiful photographic plates accompanying Dr. Johnston-Lavis's work on "The South Italian Volcanoes."[2] An explosion has just occurred in the crater of Vulcano, one of the Lipari Islands, and the dense cloud of steam and dust, at first rushing vertically upwards, is now being carried along almost horizontally in the air. The last great eruption in this island occurred on August 3rd, 1888, when, among other striking manifestations, a block of lava thirty feet in diameter was thrown three-quarters of a mile from the crater, penetrating the volcanic soil to a depth of ten or eleven feet. Prior to January 26th, 1886, chemical works existed in the crater; the gaseous products rising through the fissures condense and even interact on one another, so as to cause a deposition of various salts of commercial value, which were collected at their point of origin. But on the date named these adventurous works were blown into the air, and the volcano has since been fairly active. In March 1890, for instance, it broke the windows of houses in Lipari by casting stones against them across a distance of four and a half miles.[3]

[1] See *Nature*, vol. xxxiii (1886), p. 483; review of work by Dr. Riggenbach.

[2] Published by F. Furchheim, Naples.

[3] L. W. Fulcher, "Vulcano and Stromboli," *Geol. Mag.*, 1890, p. 347; and Johnston-Lavis, *Nature*, vol. xlii, p. 78.

So much for the explosive stage of volcanic eruptions. But we all know that lava is often caused to well up comparatively gently, to fill the crater, and finally to flow over as a **lava-stream.** Or it may burst out at some fissure opened in the lower part or in the flank of a volcanic mountain, and may thence run slowly but irresistibly down into the hollows of the country. Stream-cuts may in this way be

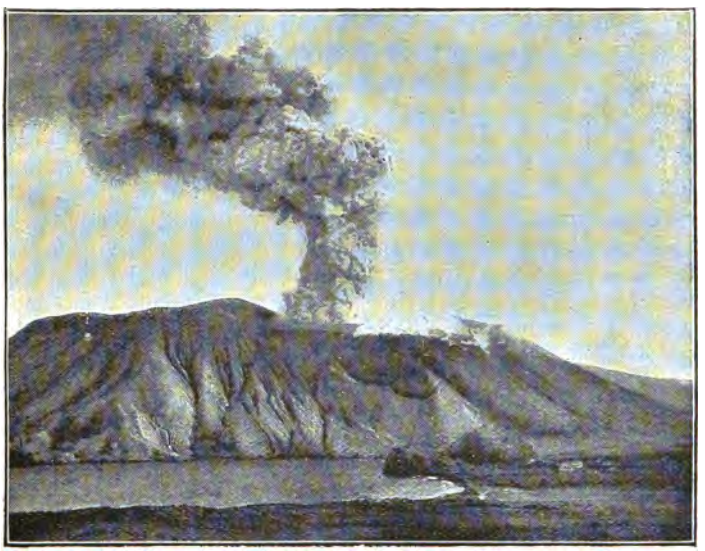


FIG. 11.—THE ISLAND OF VULCANO IN ERUPTION, February 14, 1889, 4.15 P.M.
(*Photographed by Professor O. Silvestri.*)

filled up and obliterated, while cultivated lands are often rendered useless, until denudation and decomposition have formed a new soil from the surface of the consolidated flow.

Such lava-streams give off steam and other gases while they are moving, and clearly it is the imprisoned water that has raised them to the mouth of the volcano and has forced them out steadily in an oozy flow. Earth-pressures in the slowly moving crust may also urge on the viscid mass when

once an orifice has been found. Professor Judd[1] regards the quantity of water present as of great importance in determining whether violent shattering action takes place, giving rise to volcanic dust, or whether, when it is in smaller amount, quieter upward propulsion occurs, such as gives rise to lava-streams.[1] In either case the products, having once been molten in the earth, are spoken of as **igneous rocks.**

The temperature of lava-streams may reach 1200° C. or more; but the mass is usually stiff and pasty in its flow. In the crater of Kilauea, in Hawaii, there is a lava-lake of exceptional liquidity, a condition probably due to very high temperature. The proportion of water does not seem to be concerned in this case, as very little steam is given off from these Sandwich Island lavas. This lava-lake was recently[2] 2500 feet or so across, and the movements of its surface have again and again been compared to those of water. In an article in the *Hawaiian Gazette* of July 24th, 1894, there is a remarkable account of the changes accompanying a fall in the level of the lava. "From about noon until eight in the evening," says the writer, "there was scarcely a moment when the crash of the falling banks was not going on. As the level of the lake sank, the greater and greater height of the banks caused a constantly increasing commotion in the lake as the banks struck the surface of the molten lava in their fall. A number of times a section of the bank from 200 to 500 feet long, 150 to 200 feet high, and 20 to 30 feet thick, would split off from the adjoining rocks, and with a tremendous roar, amid a blinding cloud of steam and dust, fall with an appalling down-plunge into the boiling lake, causing great waves to dash into the air, and a mighty 'ground swell' to sweep across the lake, dashing against the opposite cliffs like storm-waves upon a lee shore."

Some of the masses which thus fell in from the sides floated on the liquid lava, being probably scoriaceous, and thus distinctly lighter, despite their solid state. One huge block is described as "plunging out of sight beneath the lava. Within a few moments, however, a portion of it, approximately 30 feet in diameter, rose to an elevation of from 5 to 10 feet above the surface of the lake, the molten lava streaming from its surface, quickly cooling, and looking like

[1] Krakatoa Rep. Roy. Soc. Committee, p. 46.
[2] See *Nature*, vol. l (1894), p. 483.

a great rose-coloured robe, changing to black." Many of us will be acquainted with various popular accounts of the jets of lava thrown up from this extraordinary lake, which resemble fountains, and which are scattered by the wind into showers of tiny globes and threads of glass.

In ordinary volcanoes the lava is, as we have said, far more viscid than at Kilauea. But its rise and fall within the crater may similarly eat away the crumbling banks, and at last a breach may be effected, the wall of the mountain may give way, and the lava-stream may thus begin to flow.

There seems no reason, from what we have already said, why volcanoes should break out upon the summits of hills. Indeed, numerous cases are known where the base of the volcanic mountain has been the seat of explosive operations. But conical masses, with a crater at the top, are certainly typical of volcanic action ; and they are, in fact, built up by the products of that action.

The bombs and scoriæ which fall around the vent do so in a fairly regular ring. On the inner side this heaped-up and increasing ridge slopes inward towards the vent, and newly added fragments are constantly slipping down and are ejected a second time, or are melted up in the central lava-column. On the outer side there is also a slope, somewhat more gentle, steep at the upper part, and then descending in a long and usually concave curve to the ground through which the volcano broke. These sweeping concave slopes are among the most beautiful forms to be found in any landscape. The rain spreads the finer ash at the base of the pile still farther from the centre, while the steeper upper rim is constructed of coarse scoriæ. The rougher and the coarser these materials are, the steeper will be the slope, up to perhaps as much as 40°. Irregular heaps of still greater angle may be locally formed, by materials falling on one another in a state of partial fusion.[1]

This ridge of double slope, encircling the centre of eruption, is the simplest type of volcanic mountain. From a low ring it developes into a lofty cone, on which vegetation begins to climb. The scoriæ suffer from atmospheric attack, and soils are formed for grass and even for trees, which cling to the somewhat treacherous slope. In some places *lava-cones* are formed, far less steep in outline, by the continual

[1] See J. W. Judd, "Volcanoes," p. 153.

overflow of the molten rock, now on one side, now upon another. In the case of the recent overflow of the lava-lake in the crater-floor of Kilauea, the material washed across the rim on all sides and rapidly made raised banks around the lava-basin. When the lava sank again, as above described, it was these banks that gave way with such magnificent and spectacular effect.

Ordinarily, the crater-ring, the growing volcanic mountain, will be formed by a variety of actions, and lava-flows will roll across the ashes here and there, compressing and consolidating them, to be in turn covered by loose scoriæ. The prevalent winds may cause a heaping up of the fragmental materials on one side rather than on the other, and the crater-edge will become irregularly raised. The whole mass will form a **volcanic cone**; the mountain is, in fact, the result of the volcano, though it is in no way necessary to its origin.

The accumulated mass is, in the end, an obstacle to continued activity. It may become so vast that the steam-pressure or earth-pressures below can no longer force the lava to the summit of the elongating pipe. Consequently outbreaks may occur upon the flanks; the cone may be cracked by the final explosion of long-imprisoned gases; and sheets of lava may be forced into the fissures, consolidating there in wall-like masses and helping again to strengthen the whole mountain.

These sheets (fig. 13), crossing the bedding of the rocks on which the volcano has been piled, and also that of the ashes and the lavas of the cone, are called **dykes**, from the fact that they weather out, after the volcanic action has died away, as approximately vertical wall-like masses. They give off little ramifying sheets and threads into the surrounding rocks, and these less regular offshoots are known as **volcanic veins**. Often the lava finds its way along the stratification-planes of the previously formed rocks; we know how easy it is to slip even a thin and yielding sheet of cartridge-paper into its place amid a pile of others which it seems quite difficult to lift. Earth-movements may assist this intrusive process, by slightly arching the strata away from one another; and the lava may flow on underground for miles along the plane of weakness. Such masses are called **intrusive sheets**; they are, as it were, dykes which do not cross the bedding; and sooner or later, as we trace them out along a denuded

surface, we shall find them behaving as true dykes, either where they have split into two or more sheets, or where they join up with the main line of fissure leading to the lower regions.

Where the molten rock of a dyke reaches the surface, its included water will rapidly throw up a series of lava-cones or ash-cones, which are thus arranged along the line of fissure. Or the lava may break out at one point of weakness only, and single subordinate cones will thus arise on the flanks of the greater volcanic mountain.

A good example of the linear arrangement of cones

FIG. 12.—SMALL CONES THROWN UP ON ETNA, ERUPTION OF 1892.
(*From a photograph.*)

occurred on Etna in 1892, where four craters were constructed along a fissure which had already opened actively in 1886 and 1883[1] (fig. 12). These new hills have been named the Monti Silvestri. Monte Gemmellaro, erected also on the flank of Etna, and 1500 metres above the sea, was formed as a bold detached cone in 1886. Sixty-six million cubic metres of scoriæ are calculated to have been piled around its vent, forming a new hill 140 m. (459 feet) in height; and the whole of this was built up by the explosions of twelve

[1] G. Platania, in *Nature*, vol. xlvi (1892), p. 545.

days, the mass thus growing in height about nineteen inches in an hour.

Thus mountains may be visibly constructed on the surface of the earth at a very rapid rate. Another well-known historical case is that of Monte Nuovo, on the Bay of Baiæ, near Naples, a scoria-cone which was built in 1538 to a height of 440 feet in two days, the greater part of the work being done in twenty-four hours. Izalco, in central America, began as an opening in a plain in 1770, and the cone is now 3000 feet in height.

From these simple cases it does not require any stretch of imagination to see how huge complex volcanoes may be built up. Could we cut such a one in half (fig. 13), we should find the central pipe or neck, filled probably with a plug of consolidated lava; the beds of ash would slope upward from this on either side, following the lines of the crater-wall, and would then dip away from the neck in a somewhat gentler slope, parallel to the outer surface of the mountain. Hard ribs of lava, the dykes, would occur, crossing our section at various angles, some coming from far below the base of the volcano, others arising from the volcanic neck itself; while many of these would be seen to have sent off intrusive sheets, penetrating between the ash-beds of the cone. Lava-flows would also occur, forming compact bands among the ashes, and extending to various distances, according to their original degree of fluidity. A number of minor or "parasitic" cones, of similar or simpler structure, would appear rising upon the flanks of the main one and complicating its otherwise regular outline.

The crater of a volcano is liable, as we have seen, to *breaching* by the pressure of the lava within it; it is also frequently enlarged by the violent and explosive phases of volcanic action. The whole upper portion of the cone may become blown away, perhaps in a few hours, and a wide crater-ring will be left, the central hollow of which is due to this vehement excavation. Subsequent milder action will build up a new cone in the centre of this area; its sides will in time unite with those of the older mountain; and thus the former dignity of the mass will be restored.

Vesuvius itself is a comparatively recent cone raised in the shattered crater of Monte Somma. At present every eruption tends towards bringing the surface of Vesuvius nearer to

the earlier crater-wall, until a handsome and uniform mountain will again be constructed. A volcano may, however, occasionally go too far, and may leave scarcely a wrack behind to tell the long history of its laborious up-piling. Krakatoa had been already injured by violent explosions which took place in prehistoric times, and showed traces of a crater of excavation some three or four miles in diameter.[1] It had begun to fill up this hollow by the construction of several new cones, one of which, on the edge of the crater, rose to 2623 feet above the sea. Between May 1680 and May 1883 the volcano seems to have been dormant; but the eruption of ash in the latter year culminated in the terrific explosions of

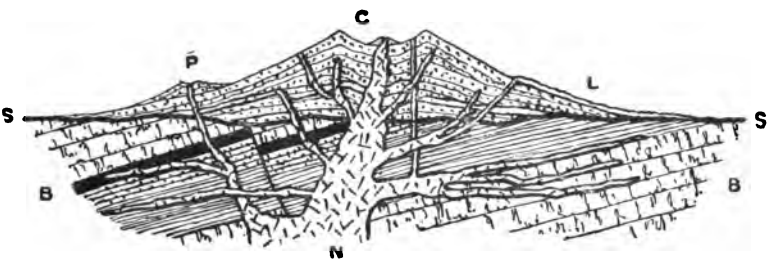


FIG. 13.—SECTION OF A VOLCANO.

B, the beds through which the eruptions have broken; C, the crater; L, a lava-flow; N, the main volcanic neck; P, a "parasitic" cone; S, the old land-surface.

August 26th and 27th. On these days two-thirds of the island of Krakatoa, and the whole smaller island of Polish Hat, were blown into the air, 18 cubic kilometres of rock, or 4½ cubic miles, being thus suddenly removed; and a hollow descending 1000 feet below the sea was formed on the site of land which a day or two before rose from 300 to 1400 feet above it.

Those sensation-loving persons who are apt to charge Nature with being far too slow in her operations will surely find some comfort in a catastrophe of such startling magnitude. The rapid construction of volcanic mountains, on the

[1] J. W. Judd, "Krakatoa Report, Roy. Soc. Committee," p. 7.

other hand, explains those tales of old travellers and sea captains about "islands that have risen from the sea." Volcanoes break out on the sea-floor as well as on the land; there being no true "burning" about them, no true combustion, a supply of air is unnecessary for their activity. Hence a cone may be built up towards the sea-level, and may ultimately overtop it, forming a steaming volcanic island. Often such loosely piled masses have been washed away again by the waves, as was the case with Graham's Isle, which was formed between Sicily and Pantelleria in 1831. This island appeared on June 18th and vanished on December 28th, having at one time a well-formed and active crater. It represented the summit of a cone at least 240 metres (787 feet) above the floor of the Mediterranean. After being cut down by the sea, it manifested itself again in 1863, after thirty-two years of quiescence, and rose to about 70 metres above sea-level; but this attempt at island-making was also unsuccessful. In October 1891 another submarine eruption occurred in this same restless area, the floating bank of black scoriæ formed above the eruptive centre being for a short time so dense as to be mistaken for an island (fig. 14). The volcanic bombs that rose freely to the surface burst there by the pressure of the gases inside them, and some actually ran hissing over the water, discharging steam.[1] The scoria-shoal broke up and drifted away at the end of October; but it is clear that the cone, which still lay far beneath it, may at any time resume its growth.

A volcano is said to have undergone **extinction** when all sign of activity, in the form of upwelling of lava in the neck, has long ceased, and when it seems to have been given over as a prey to denudation. But volcanoes may, as we have seen, remain dormant for centuries; and extinction is never abrupt, it is a very gradual process, broken at times by a startling return of the energies that seemed steadily flagging. Among the signs of waning activity, the prevalence of hot springs may be noted. In an earlier condition, steam-jets, looking at a distance like the cloud-columns of a true eruption, may occur freely from any rift in the crater-floor; and other gases, such as Hydrochloric acid, Sulphur dioxide, and Sulphuretted hydrogen, rise in a highly heated state, the

[1] G. W. Butler, *Nature*, vol. xlv, pp. 154 and 584.

latter often decomposing as it burns and depositing sulphur round the vent. These gases are given off during, as well as after, the eruptive period, and rise, with the steam, from the hot lava-flows themselves. But in time the temperature is insufficient to maintain these steam-jets or **fumeroles**, and **hot springs** take their place, the waters of which are charged with salts in solution—mostly carbonates and sulphates of sodium, magnesium and iron—and with gases, the chief of which is carbon dioxide. It is this gas which gives so bubbling and sparkling a character to the ordinary *mineral waters* placed upon our tables. The dissolved salts, varying

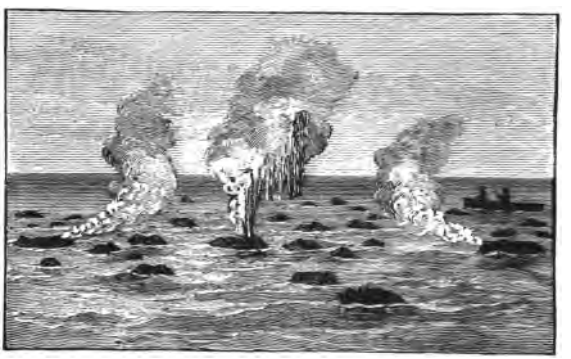


FIG. 14.—FLOATING SCORIÆ ABOVE THE SUBMARINE ERUPTION OFF PANTELLERIA, October 1891.

in different localities, give a medicinal value to many springs, and fashionable health-resorts are established on the scene of ancient eruptions. Thus, close to the charming hollow of Franzensbad, on the fringe of the Bohemian forests, near the hotels and bath-houses and promenades, there is one of the neatest and freshest little volcanic cones, the Kammerbühl, as a reminder of the origin of the springs. The form is not well retained, but a large quarry has been dug into the hill, providing a remarkable section of the layers of volcanic ash. The scoriæ are perfectly preserved, looking as if erupted yesterday; and they lie scattered also in the soil around the vent, which is now cultivated most peacefully. A bold row

of fir-trees running up the back of the cone looks greatly out of place. In the well-marked beds of scoriæ, there lie numerous flakes, baked and reddened, of the old granitic rocks which form the floor through which the eruption broke.

To make things more complete, a dull grey lava-flow runs down one flank of the Kammerbühl, showing another phase of the activity of the cone. The whole thing might easily have been constructed by the explosions of any twenty-four hours.

Some mineral springs of volcanic origin are by this time fairly cold; but others have retained their heat in a most interesting degree. Some, like the explosive **Geysers**, are thrown up by outbursts of steam, occurring at regular intervals. The water acts like the lava-scum in the vent of a volcano, and the steam, forming and accumulating in the hotter regions at the base of the pipe, finally overpowers it and flings it in a foaming column into the air. A beautiful little European geyser is to be seen in the source of the Sprudel at Karlsbad, in west Bohemia, where the water is thrown up to a height of ten or twelve feet some thirty times a minute. Its temperature is 162° F., and it still forms a delightful spectacle, although tamed and hemmed in by a marble basin and an ornamental hall of iron columns.

In our own islands we still have the famous springs of Bath, with a temperature of about 115° F. The salts included in their water amount to 168 grains per gallon, or as much as .204 per cent. 94 grains per gallon consist of calcium sulphate; sodium sulphate furnishes 23 grains, and magnesium and sodium chlorides each 15 grains per gallon.

Thus we have very briefly glanced at the life-history of volcanoes, such as are at present active on the earth. We have marked their growth, the occasional accidents that impair their symmetry, and the features of their period of decay. We can now look at their products more in detail, so as to be able to recognise them in regions from which volcanic activity has for long ages happily disappeared.

All known lavas, whether in the form of fine ash, or scoriæ, or massive flows, are found by chemists to consist of silicates. Some contain 75 per cent. of silica, others as little as 35, the substances combined with this prevalent

oxide being oxides of aluminium, potassium, sodium, calcium, magnesium, and iron. We cannot say in what relations these various bodies exist when the whole is one molten mass within the volcano; but, on cooling, crystals of definite minerals begin to separate out. If cooled rapidly, as on the walls of many dykes, or by contact with the air, the lava forms a glass, varying between black bottle-glass and the duller glass of iron-slags, such as one may pick up near furnaces in the English Midlands. Yet this glass is never free from tiny beginnings of crystallisation. When sections of it are prepared for the microscope (p. 25), minute imperfect groupings of crystalline particles are seen, these embryonic crystals being called *crystallites*. Most crystallites are rod-shaped, and they become aggregated, in the hurried process of development from the glass, into more or less regular tufts and bunches. Sometimes they manage to take up true crystallographic positions with regard to one another, a number building up what is styled a *skeleton-crystal*. Very often they cluster round some central body and arrange themselves radially about it, so as to form a little sphere, built up of fibres all pointing inwards towards the centre. Such bodies, often 2 mm. to 1 cm. in diameter, and sometimes even reaching 1 metre, are known as *spherulites*, and are very characteristic of glassy rocks. Where artificial glass has remained a long time at the bottom of the tank in which it is being made, and has been subject to various coolings and reheatings, spherulites often develop, appearing as little white balls, with radial structure, in the midst of the pale green or black-green glass.

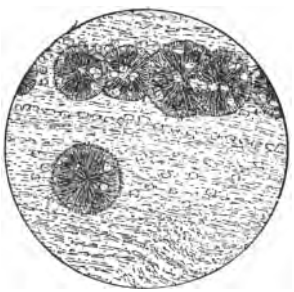


FIG. 15.—MICROSCOPIC SECTION OF VOLCANIC GLASS (RHYOLITE-OBSIDIAN) FROM THE YELLOWSTONE PARK, UNITED STATES, × 12, showing spherulitic, fluidal, and banded structures.

The dragging movements that go on while volcanic glass is cooling set up a *fluidal structure* in the mass; the material is still in motion, and the crystallites and spherulites are carried along, often forming distinct bands. Part

of the natural glass from a lava-stream in Lipari thus consists of alternate layers of black glass and creamy white closely set spherulitic matter. Such rocks are said to have a *banded structure.*

The best known volcanic glass is **Obsidian** (fig. 15), named after Obsidius, an antique Roman who is said to have brought it from Asia Minor. The ingredients are such as a professional glass-maker would employ (see Analyses I. and II.), with the exception of some 14 per cent. of alumina. When the proportion of silica in the molten lava is less than 65 per cent., the chances of the production of a glass are much reduced, crystallisation then setting in more rapidly and the whole mass becoming dull and stony. Occasionally glasses are formed, however, out of difficult combinations of oxides, as is seen by the third analysis given below. In this case very complete fusion and rapid cooling seem to have worked together to produce crusts of glass some 2 inches thick upon the surface of the Hawaiian lavas. But the glassy mass dealt with in the second analysis is from 100 to 160 feet thick, with a few spherulites an inch across in places, and a number of more typical small ones (see fig. 15).

ANALYSES OF ARTIFICIAL AND NATURAL GLASS.

	I. British Plate-Glass, St. Helen's. Analysed by Mayer and Brazier.	II. Obsidian, Obsidian Cliff, Yellowstone Park, U.S.A. Analysed by Hague.	III. Average of 12 Hawaiian Glassy Lavas, analysed by Silvestri.
Silica	77.36	74.70	48.25
Alumina	trace	13.72	15.65
Iron Oxides	0.91	1.63	16.59
Lime	5.31	0.78	8.40
Magnesia	...	0.14	3.70
Soda	13.06	3.90	3.62
Potash	3.01	4.02	1.57
Other substances and loss on ignition (water, carbon dioxide, &c.)	...	1.02	0.41
Total	99.65	99.91	98.19

Almost all lavas contain a little glass, which has not had time to become entirely converted into crystallites. But as the mass cools more slowly, steadily parting with its imprisoned water, crystallisation goes on, until the products are visible to the naked eye; well-developed crystals are thus formed, instead of mere tufts and spherical groups of crystallites. In microscopic sections, these crystals of various silicates are seen fitting into one another, those of the last-formed minerals often enclosing the earlier ones (fig. 16), while here and there a little glass, dusty with crystallites, remains between the mesh of crystals.

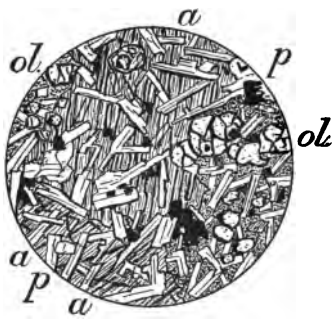


FIG. 16.—MICROSCOPIC SECTION OF LAVA (BASALT), FROM TOBERMORY, MULL, × 25, showing augite (*a*) enclosing plagioclase (*p*) and olivine (*ol*). A part of the glassy groundwork, full of minute dust-like crystalline particles, appears on the right.

The larger crystals often seen in lavas, and even entangled in the silky fibres of pumice, are styled *porphyritic*, since the rocks known to the ancients as "porphyries" are thus stuck full of crystals which are more conspicuous than those of the compact groundwork of the rock. Porphyritic crystals are seen, on minute examination, to be cracked and broken, and are often eaten into by the glassy matter of the lava. In sections they even look like lumps of sugar that have just begun to dissolve. Such crystals, often the most attractive objects in the rock, cannot have developed during the consolidation of the lava as we now know it, but have been formed in an earlier stage of consolidation and crystallisation underground, where the greater pressure, slower cooling, and perhaps the presence of water, allowed of their production on a handsomer and coarser scale. Then, by relief from pressure, or by further heating, or by the introduction of additional water, which assisted the mass to become more fluid, the lava ceased for a time to consolidate, moved forward, and floated the crystals already formed up with it to the surface. Some were no doubt completely redissolved; and those that remained

show, as we have said, signs of having been vigorously attacked.

Porphyritic crystals are often, however, the relics of other rock-masses which have been picked up and partly melted by the lava on its way, certain mineral constituents alone remaining. Thus some lavas have become studded with quartz-grains derived from beds of sandstone through which they have been erupted.

In the lavas fairly rich in silica, the following minerals may separate out on cooling from the mixed ingredients of the molten mass:—Quartz, Orthoclase, Albite, Oligoclase, Biotite, Hornblende, Augite (commonly a variety rich in soda). In those rocks poorer in silica, we have typically Labradorite, Anorthite, Biotite, Hornblende, Rhombic and Monoclinic Pyroxene, Olivine, Magnetite. In the ordinary lava of Vesuvius, Leucite in part takes the place of the felspars which so commonly prevail in other lavas. Leucite contains the constituents of orthoclase, but the proportion of silica in it is far less.

Thus lavas, when crystallisation has set in, are seen to consist of mineral silicates, with one or two common representatives of the oxides, such as quartz and magnetite. Carbonates, sulphates, sulphides, chlorides, could not well exist at such high temperatures on the earth's surface; and, as we have seen, the more volatile constituents of the crust come out as gases during volcanic eruptions, and continue to do so long after the lava itself has sunk into the condition of a cold and solid rock.

There are four broad types of lava that are most commonly met with:—

1. **Rhyolite.**—The chemical composition of this rock is well shown by the analysis of obsidian, a glassy form of it, given above. Its name, meaning "flow-stone," refers to the frequency with which flow-structure and banding are observable in it (fig. 15). It is usually a pale yellowish white or pink rock, being poor in iron; and its composition causes glassy forms to be common, which are distinguished by their superior transparency in thin splinters and by their low specific gravity from glasses with a less amount of silica. In its "stony" form, when the groundwork is a crowded mass of crystallites, rhyolite has a specific gravity of 2.5; in its most glassy form, the obsidian-type, it is as low as 2.3.

The crystals most likely to develope distinctly in rhyolite are Quartz, Orthoclase, Biotite, and sometimes Pyroxene rich in soda.

2. **Trachyte.**—In this lava only some 60 to 65 per cent. of silica is present, but potash is still an important constituent. The name refers to the "rough" (τραχύς) texture of the rock, in distinction to the compactness of most basalts. The colour is usually white or grey; its glassy forms resemble those of rhyolite, but are of higher specific gravity, the obsidian-type being about 2.4. The "stony" type of the rock gives about 2.55. The groundwork is most often formed of a mesh of minute crystals of orthoclase, with soda-pyroxene, hornblende, or mica; larger crystals of orthoclase, transparent and glassy-looking in modern examples, are scattered abundantly through this ground.

3. **Andesite.**—In these rocks the silica may amount to even 70 per cent., but is sometimes as low as 55; soda always predominates over potash, and lime is prominent in those varieties containing little silica. The essential difference from the rhyolites and trachytes is that in the andesites plagioclastic (triclinic) felspars crystallise out in place of orthoclase. The name refers to the abundance of this type of lava in the Andes Mountains. At one end of the great Andesite series we have light-coloured and even glassy lavas, like trachytes in appearance; in these the silicates of magnesium and iron are not abundant, and albite and oligoclase felspars, and even quartz, may crystallise out. At the other end of the series we have dark grey and black rocks, resembling basalts; the glassy types among these are rare, and almost dull, crystallisation setting in so easily during cooling. These andesites, with some 58 per cent. of silica, contain lime, magnesia, and iron oxides, in greater abundance than is the case with the trachytic type; and consequently black augite and rhombic pyroxenes often crystallise out, while the iron oxides that are uncombined with silica form magnetite. The felspars, whether forming a mesh in the compact ground or developed porphyritically (p. 167), are likely to be labradorite rather than oligoclase. The specific gravity of andesites, when fairly crystalline, rises from 2.65 in the types rich in silica to 2.9 in those allied to basalt.

4. **Basalt.**—The Andesites and the Basalts are probably

by far the commonest lavas on the face of the globe. The percentage of silica in basalt runs from about 40 to 55; iron oxides and magnesia and lime may now make up one-third of the rock's weight, or 33 per cent., while in the rhyolites they often are below 4 per cent. Glassy types are very rare; an analysis, No. III., has been given on p. 166, which will serve to show the composition of basalts in general. The name Basalt is an ancient one, and is claimed by Pliny as of Egyptian origin.

The groundwork of the rock is dark grey or black, typically compact, and breaking almost like flint in the most finely grained varieties. There is a minutely sparkling effect over any freshly broken surface, which is produced by the glancing of the little crystals, so abundantly formed throughout the ground. Olivine may occur in porphyritic crystals, and the presence of this mineral furnishes, as Professor Judd urges, the best distinguishing feature between typical basalts and the andesites poor in silica. But often the olivine may be decomposed, or may be visible only on microscopic examination (fig. 16). Labradorite and anorthite felspars are common as porphyritic constituents, and one of these always forms a great part of the groundwork, together with little granular augites. Sometimes, as shown in fig. 16, the augite forms round and encloses the tiny rods of felspar. Magnetite separates out freely. The large amount of iron present causes surfaces of the rock to decompose on weathering with a marked rusty brown colour; while the silicates of iron and magnesia alter to serpentine and chlorite, and colour the interior of the mass a dull and variable green. Thus basalts often become quite soft and friable through the easy decomposition of their constituents. The specific gravity of typical fresh basalt is close on 2.9.

To sum up, we may classify our lavas thus in a table:—

Name.	Approximate Percentage of Silica.	Minerals typically produced in slowly cooled varieties.	Approximate Specific Gravity of more crystalline varieties. (See also Table on p. 206.)
Rhyolite	70	Quartz, Orthoclase, and Soda-pyroxene.	2.5
Trachyte	65	Orthoclase and Soda-pyroxene (or Hornblende, or Biotite).	2.6
Andesite (*a*) Type rich in silica.	65	Albite (or Oligoclase) and Soda-pyroxene (or Hornblende, or Biotite).	2.7
(*b*) Type poor in silica.	55	Labradorite and Augite (or Rhombic Pyroxene); Magnetite.	2.8
Basalt	50	Labradorite (or Anorthite), Augite, Olivine, and Magnetite.	2.9

All lavas are likely to have certain characters impressed upon them during consolidation, apart from the occurrence of more or less complete crystallisation. We already know that their upper surfaces may be scoriaceous, owing to the escape of steam and the formation of abundant bubbles. The cavities thus formed have smooth inner surfaces, and are often beautifully regular and elliptical, being, in fact, spherical gas-bubbles which have been pulled out in one direction by the flow of the lava. Owing to the rolling over of the advancing front of the lava-stream, the scoriaceous upper layers become carried to the bottom of the flow; and the lava-stream moves on over them and thus becomes coated on both surfaces with broken bubbly material. These surfaces, being products of fairly rapid cooling, will be the most glassy portions of the flow; and more and more completely crystal-

line material will be found, after consolidation, towards the interior of the stream.

Another striking character is the **columnar jointing** of lavas. The rock becomes reduced in volume by contraction on cooling, and also by the loss of its water in the form of steam. A fairly regular series of joints is consequently set up in it, and the most common result is that the rock splits into a number of six-sided columns. Similar columnar jointing can be seen where clay has been dried by the sun upon a beach, and also in the starch used for domestic purposes. Clearly the structure is due to mere contraction, and not to any process of crystallisation.

Now, the upper layers, cooling from the highest downwards, exposed as they are to variable air-currents, and giving off gases somewhat rapidly, split into a large number of less regular and smaller columns, lying in many different directions; or they may merely settle down finally as a compact and somewhat scoriaceous mass. But the bottom layers, cooling from the lowest upwards, take far more time over the operation; and columns more than a foot across may arise by the process of "starring" against the colder ground-surface, and may spread upwards, as the whole mass cools, into or beyond the centre of the lava-stream. The outcome of these two modes of cooling, meeting in the interior of the mass, is that a large lava-flow is divided into a compact or only feebly columnar upper portion, and a handsomely columnar lower portion, any natural sections that may be formed showing us this striking contrast of the two layers. The columns starting from the ground are perpendicular to that fixed surface of cooling, and have all the appearance of well-trimmed masonry. Cross-joints, curved upwards or downwards, divide these columns into blocks resembling the "drums" of ancient pillars. It is no wonder that primitive peoples saw in such a regular structure in the solid rock the work of giants who built causeways in this lordly fashion. Later observers may also be excused for regarding the columns as some form of gigantic crystal.

At the island of Staffa, the sea has quarried away the easily detached lower columns of a lava-flow, and has excavated caves, the compacter upper layer holding itself together and serving as a roof. At a distance one can hardly believe that rocks of such distinct structure are

COLUMNS AT THE GIANT'S CAUSEWAY, Co. ANTRIM, IN BASALTIC LAVA-FLOW.

PLATE VI.] [*Photographed by* Mr. R. WELCH.

merely the regularly and the irregularly cooled portions of the same flow. At the Giant's Causeway, on the north coast of County Antrim, the rougher surface of a fine flow has been removed by weathering, and the ends of the columns of the lower part form a seaward-stretching terrace of wonderfully regular structure. When we look down upon them (Plate VI), they seem to form a tessellated pavement, the curving cross-joints sometimes appearing as flattened domes, sometimes as shallow cups in which rain-water and sea-spray collect.

Any fair-sized dyke will similarly show columnar structure due to its contraction (Plate VII). But in this case the two surfaces, if in contact with the same kind of rock, are under the same conditions of cooling. Often we have a selvage of glass on each side, perhaps a mere film only discoverable by careful search; this outer portion is broken by a large number of small closely set joints, and is usually friable in consequence. Then comes a region of partial crystallisation, the rock being flinty and compact, with columns developed perpendicular to the surfaces of cooling. The central region is often completely crystalline, the columnar structure there being coarser.

The columns in dykes thus start independently from opposite sides and meet along a central plane, which consequently becomes a source of weakness in the mass. Weathering action attacks this plane, and sometimes the dyke becomes decomposed from its core outwards, leaving a gully to mark its former position, instead of standing out like a solid wall. Intrusive sheets possess similar characters, only here the columns are formed perpendicular to the planes of bedding.

Another form of contraction which is very common in lavas and intrusive masses is the tendency to produce spheroids, which often lie one within the other. In its common and coarse variety, this **spheroidal structure** gives us a number of pillow-like masses, fitting into one another, like so many loosely packed sacks of grain heaped casually together. In its more perfect form, the rock has contracted in a series of concentric shells, which are often emphasised by the brown stains produced through the infiltration of rain-water. The resulting globes can be pulled out of the mass and easily broken up into concentric fragments with

the hammer. Many basalts show this structure upon weathering; and in the island of Ponza, west of Naples, a greenish columnar obsidian occurs, the columns subdividing into globes 3 or 4 inches to 3 feet in diameter.[1]

Well-marked spheroidal structure occurs commonly in the interior of the columns produced by previous contraction; and the curved cross-joints already noticed at the Giant's Causeway and elsewhere are a manifestation of the same tendency. **Perlitic structure** is a minute spheroidal structure occurring only in glassy rocks, often in great perfection. The rock becomes broken up by it into little pearl-like masses, formed of concentric coats like those of an onion, these globes being only about 2 mm. in diameter.

Dykes and intrusive sheets naturally bake and alter the rocks on both sides of them; but lava-streams can only affect the bed below them, and that merely in a slight degree. This fact is at times of service in determining whether some ancient volcanic mass is a flow or an intrusive sheet. If the former, it is of the age of the deposits in which it is found embedded; if the latter, it may be of any age later than those deposits, and other evidence as to its exact period of formation must be looked for. A maximum age for an intrusive rock can often be arrived at by the discovery of pebbles worn from it lying in some neighbouring conglomerate. Clearly the rock was cold and denuded before this conglomerate was laid down.

Now let us return to our high bleak plateau of Auvergne, armed with these ideas as to the characters of modern volcanic action. It was thus that MM. Guettard and Malesherbes approached the problem a century and a half ago; and there is little difficulty now in recognising the Puy de Pariou as the scoria-cone of an extinct volcano. On the north-west side, moreover, we have already noticed a distinct semicircular rampart, and this represents an older crater-ring on the ruins of which the Pariou has been thrown up. Eastward from this earlier crater, there stretches a rugged surface of grey rock, confused and broken, descending over the steep edge of the plateau towards Clermont. This can be nothing else than a huge consolidated lava-flow, which has breached the older cone.

[1] G. P. Scrope, "Notice on the Geology of the Ponza Isles," *Trans. Geol. Soc. London*, ser. 2, vol. ii (1824), p. 205.

We can follow out the course of this magnificent mass of andesite, as it rolled at red-heat across the granite slopes; we can see where it struck on a knoll at La Baraque, still looking, as Scrope says,[1] like "a huge wave about to break over the seemingly insignificant obstacle." Here it split into two narrow flows, the velocity of which must have been considerable, as they hurried down the valleys already cut in the plateau-face. One of these tongues reached nearly to the site of Chamalières, the other to that of Nohanent, in each case a course of about 8 kilometres from the shattered cone of Pariou. Near Chamalières the end of the flow rises in a steep and rugged front; and beneath it are the remains of a wood which it bore down upon and overwhelmed.

Several quarries in this lava-flow have revealed its inner structure; its upper and lower portions are distinctly scoriaceous, while the centre is only minutely so, and is, as we should have expected, of compacter texture. The northern branch, exposed in the Durtol quarries, is exceedingly compact and altogether darker in its colour.[2]

When we become accustomed to the features of this highland of Auvergne, we shall easily pick out the lava-flows with the eye, by their rugged surfaces of confused grey blocks, their scoriaceous texture, and the fact that they are often abandoned to a growth of wild underwood and forest. The Puy de Louchadière, one of those whose tops we can just see beyond the Puy Chopine, will thus well repay a visit. The huge scoria-cone, 1300 feet above the plateau, is breached on the west by a flow of basalt, up which a track now wanders into the crater. But the mountain itself is piled upon earlier flows of andesite, which have become somewhat smoothed down, but which may be traced away into the hollow of Pontgibaud. Farther south, two flows, each one and a half miles wide, form rugged and tree-covered slopes descending from the Puy de Côme; the most northern branch of these, reaching Pontgibaud, has been there cut into by the river, the columnar structure of its basal layers being revealed.

The most delightful of breached cones are a pair lying east of the quaint little hamlet of Nébouzat; and we must

[1] "Geology and Extinct Volcanos of Central France," p. 63.

[2] For a minute description of these rocks, see Von Lasaulx, "Études pétrograph. sur les roches volcaniques de l'Auvergne," 1875, translated from the German by F. Gonnard, pp. 55–72.

climb the Puy de Vichatel or some neighbouring height to view them. The Puy de Lassolas and the Puy de la Vache then appear as two bare pink-brown scoria-cones, broken open completely on the south side, and giving out a flood of lava (fig. 17). The puys beyond them are grass-covered, with the denuded rock of the Puy de Dôme rising palely in the background; and these red and loosely piled masses in front of us look as if they had been thrown up only a year or two ago. But the lava-flows, uniting on the plateau, are covered with characteristic woodland, in which the grey scoriaceous blocks of basalt stand up like the *débris* of a landslip. The course of the joint flow, with its offshoot to the left,

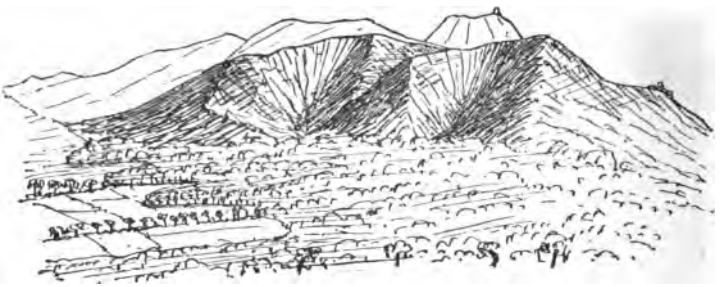


FIG. 17.—THE PUY DE LASSOLAS AND THE PUY DE LA VACHE, FROM THE PUY DE VICHATEL.

(*From a sketch by the Author.*)

where it struck against the puy on which we stand, is clearly marked by the line dividing the wooded country from the fields. The tumbled mass flows away to our right, where the high road has been cut through it, and falls some 600 feet into the valley of the Veyre (fig. 18). Here it has dammed up the river and formed the Lake of Aydat, a good kilometre in length, the water escaping round the foremost tongue of the lava. Another lake, now drained, was formed in a similar manner farther north. This is a good example of how the face of a landscape may be changed by a lava-flow, perhaps in the course of a few hours.

Beneath this basaltic stream, which itself is three and a

half miles (5½ km.) long, an earlier one appears, running down the narrow valley to St. Amand-Tallende, some five miles farther to the east. The Veyre has partly cut its channel in this flow, and at Ponteix wanders through its

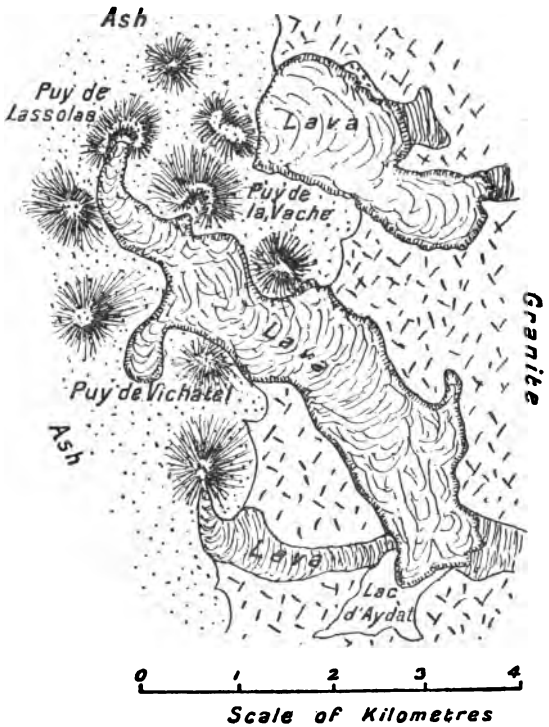


FIG. 18.—GEOLOGICAL MAP, SHOWING LAVA-FLOWS DESCENDING FROM PUYS IN AUVERGNE.

(*From Sheet 166 of the Map of the Geological Survey of France.*)

crevices; but finally it found the rock too hard for it, and made its way along the northern edge, between the lava and the soft sediments of the plain. It is thus that these rugged masses are left standing out above the general level, and are perpetuated as features of the landscape.

Within the breached craters of the Puys de Lassolas and de la Vache, the bedding-lines of the scoriæ can be clearly seen. These barren little cones, fresh and brown and sharply rimmed, despite the great outpourings of lava, form the most effective volcanic picture in the whole chain of the Monts Dôme.

If we return north to the exquisitely regular scoria-cone of the Goules, we find that it is banked against a broad pudding-like dome of trachyte known as the Grand Sarcouy, a name believed to be derived from the fact that the Romans quarried this pale rock for making sarcophagi, or stone coffins. This mass is shown above the Goules in our illustration (Plate V). The great Puy de Dôme itself is probably another but steeper mass of the same kind, and so also is the peak of the Puy Chopine, which appears over its outer rampart on the left of the Puy des Goules. These singular rocks were probably thrust up in an exceedingly pasty form, each through its volcanic vent, and became consolidated in huge domes upon the surface. The Sarcouy is certainly one of the oddest hills that it will be our lot to see; although scoria-beds occur within it, the viscid trachyte has controlled the form of the central mass now left to us. A more extreme instance appears in the brown trachytic mound of the Schlossberg, near Teplitz in Bohemia; the surface of this hill is largely controlled by the flaking off of its concentric coats, the fragments lying freely in the woods upon the lower slopes. Professor Reyer,[1] who investigated the mass, concluded that it also was a protruded dome, the successive coats naturally arising, as the new material from below welled up and stretched the older and still viscid layers which lay above. Professor Reyer has successfully imitated the Schlossberg and other domes by forcing up moist plaster-of-Paris through a hole in a board.

Far more often, lava welling up, without being blown into scoriæ by the escaping steam, forms round the vent a true and gently sloping *lava-cone*. An example of this is probably to be found in the Puy de Charade, south of Royat, where a circular area of basalt, with handsome porphyritic olivine, caps a granite knoll and flows away to the north-east. No sign of an actual crater is now visible.

[1] "Ueber die Tektonik der Vulcane von Böhmen," *Jahrb. d. k. k. geol. Reichsanstalt*, Band xxix. (1879), p. 464.

The volcanic craters of the Monts Dôme have been extinct, humanly speaking, for a long time; but man himself was probably in the country when the later scoria-cones were exploding in the height of their activity. The oldest volcanoes of the central plateau of France, those of the Cantal, do not date back farther than the Upper Miocene epoch (see p. 231); and at that time the ground on each side of the granite platform had only recently been raised above the sea. The volcanoes, in fact, were, as so often happens, the natural accompaniments of movement in the crust of the earth.

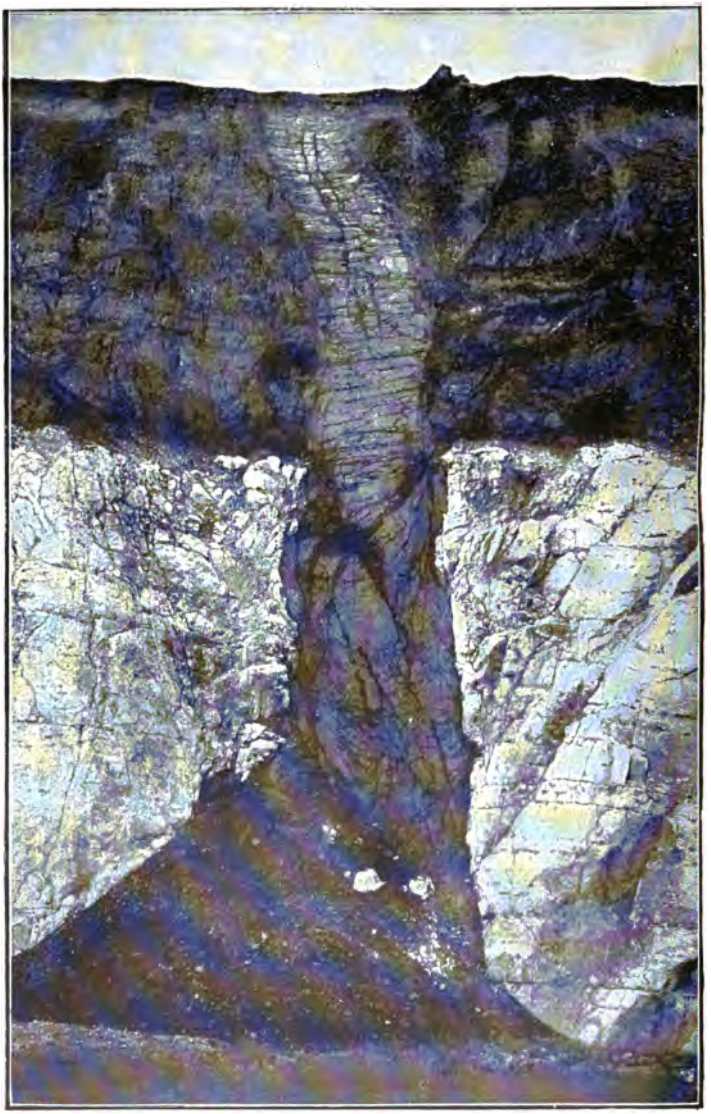
The recency of their extinction is shown by the abundance of mineral springs which still flow out at the base of the plateau, making Royat, La Bourboule, and Mont Dore famous among health-resorts. Here and there the waters have filled the craters, forming characteristic **crater-lakes.** It is pleasant to stand upon the col under the Pic de Sancy near Mont Dore, and to look over the rolling country to the south, with its fold on fold of basalt hills. In this high volcanic plateau lie several circular lake-basins, notably Lake Pavin and Lake Chauvet near at hand. Both these are encircled with crater-rings, and the loose shore of scoriæ descends with strange steepness into the calm and sheltered water. Fir-trees have crept over the shallow rim of the volcano, and have grown about the central lake. Everything to-day thus speaks of quiet and extinction.

The earliest volcanic masses, those of Mont Dore and the Cantal, though mainly Pliocene, have already been cut deeply into by denudation. At the very gate of Mont Dore, with the beautiful cones of the Monts Dôme still fresh in our memory, we pass the steep valley leading down to Rochefort, and see disconnected relics of old lava-flows left as mere patches on either side. The trachytic crags of the Roche Sanadoire and the Tuilière have been carved out of two massive dykes; they rise up like huge gate-posts flanking the valley, and are most perfectly columnar, the structure repeating itself in tiers at various angles. White taluses stream down at their feet, and proclaim the attack of weather on them. The walls of the long combe of Mont Dore are marked with layers of white trachytic tuff and dark little cliffs of andesite; the forms of the landscape no longer depend upon volcanic

accumulation, but peaks and hollows are cut regardlessly through the deposits, and a complex mountain-mass has resulted, reminding one of central Wales.

Again, in the south, beyond the denuded volcano of Mont Dore, the country is set with mere relics of the former flows, such as the high crag of Apchon, one of the most beautifully columnar basalts in the country. The peak of the Puy Mary of Cantal (5861 feet) is carved out of both andesite and trachyte; the scoria-cones have disappeared, and have left merely bands of tuffs, which are visible along the crags above the woodland. The crest of the mountain forms the centre for a radiating series of arêtes, each spreading outwards as the wall of some splendidly proportioned valley. At sunset the level light streams in from the Bordeaux plain, and fills all the western hollows with a golden haze; the shadow of the Puy Mary climbs slowly across the valley of Aurillac, and the highland-pastures, and the little huts of the cheese-makers, die slowly away into the gloom. As the silence spreads, we hear the noise of torrents more clearly from the hollow far below; the valley is almost choked with *débris*, through which the water is busily cutting a ravine. Everywhere we have the grand air of a mountain given over to denudation. In time it will be difficult to trace even the worn-down centres from which these lavas of the Cantal were erupted.

If in so short a space of geological time these volcanoes of the Pliocene period have lost all their characteristic outlines, if the crater-rings have vanished and the lavas have become dissected into fragments, it is scarcely surprising that in our own islands we have nothing that we can point to as a cone. We have volcanic relics in plenty, but the atmosphere and the sea have long worked their will upon them. Serious tourists, proud of their attainments, will point out a small grassy hollow on the top of Staffa as the crater whence the lava flowed, regardless of the fact that the whole island is a mere remnant of a stream of basalt, resting regularly upon a bed of ash. Similarly the cirques of our higher mountains are annually pointed out as craters, particularly on the front of Cader Idris. In that instance they are, like the Cantal valleys, quite unconnected with the original form of the volcano, while in a great number of cases there is no erupted matter in the neighbourhood of



DYKE OF DOLERITE, TRAVERSING CHALK AND BASALTIC LAVAS, QUARRY ON CAVE HILL, BELFAST.

The upper part is distinctly columnar. Talus at foot. The chalk shows bands of flints along the bedding-planes.

PLATE VII.] [*Photographed by* MR. R. WELCH.

these cliff-set hollows. The task of tracing out the history of one of our own volcanic areas is, however, always fascinating; and the remarkable observations of Dr. Macculloch, Professor Judd, and Sir A. Geikie, in the Western Isles of Scotland have led a number of enthusiasts into the same attractive field.

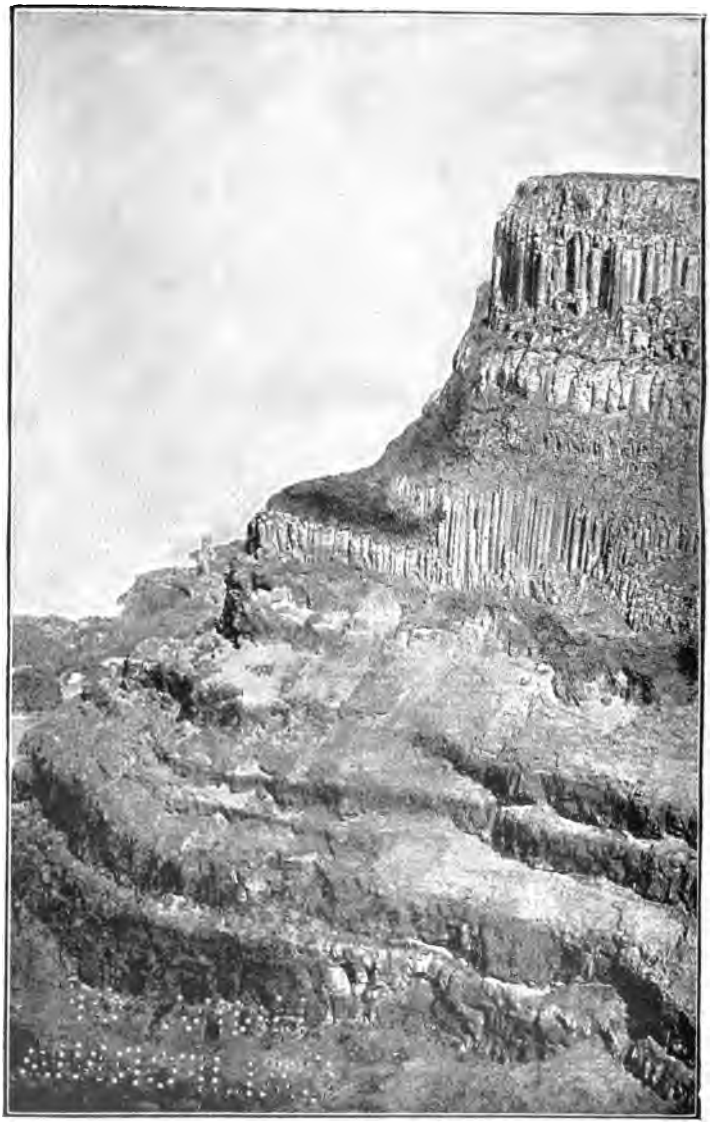
Without doubt, the most convenient region for the study of our own volcanoes is the country around Belfast. The cinder-cones have been swept away by denudation, but the volcanic necks and dykes remain. Everywhere the greater heights of County Antrim are formed by plateaux of basaltic lavas; and the contrasts of form and colour are as clear as a diagram in a lecture-room.

The coast of this fine county is strange, but always beautiful. Long slopes of red clays and sandstones lead down in places to the sea; above them here and there blue-black clays can be seen in the road-side sections; higher still, the ground rises steeply, and is quarried away, showing bands of white limestone, the chalk of Antrim. The capping of the whole is a bold dark cliff of basalt, formed of tier on tier of lava-flows, with occasional ash-beds, its jutting spurs and pinnacles weathering out in tints of ruddy brown. Beyond Larne, the white limestone, the chalk, comes down to the shore, and cliffs have been cut in it like those of south-east England; while the volcanic layers form the upper half of the wall, bare and brown and crumbling. The waters from the high basalt moorland flow down in the clearest streamlets into gullies carved out of the chalk; and the black volcanic pebbles lie picturesquely in these snow-white hollows. Every now and then a dyke is seen (Plate VII) filling some old fissure, formed in the time of disturbance and activity, and cutting both the bedding of the limestone and the oldest lava-flows above.

From the east coast right into the county of Londonderry the surface is formed of gently swelling basalt plateaux, every older feature being concealed by the union of the flows. Heather grows freely on these uplands, and peat is cut by the peasants in the broad levels of the bogs. It is a strange and often desolate landscape, nearly devoid of trees, and covered in winter with undisturbed sheets of snow. But, when we come to the plateau-edge, the scenery is rich in its variety. After the long pull across the mountain from

Coleraine, we drop steeply from the lavas to the alluvium of the River Roe; or we may come round by the coast under gloomy cliffs of basalt, all the more impressive by contrast with the recent sand-banks of Lough Foyle. Away, again, on the east of County Antrim, in the hollow of Cushendall, we see the plateaux dissected into a number of bold mountain-spurs. The cliff of basalt runs round these, making a fine outline at its angles against the sky; but the crests of the spurs are all of about one height, being formed of the broad rounded backs of the united lava-flows. Farther inland, the highest sheets of basalt, which have been denuded away from these lower ridges, form another great platform in this step-like country, reaching some 1800 feet above the sea. The glens that have been cut into them stretch down to the woodlands of Cushendall, and far older volcanic masses are exposed down there upon the shore itself. Near at hand, dominating the valley, the cone-shaped summit of Tieveragh rises, the solid neck of a volcano that has long since been worn away. In the south, across the bay, the chalk cliffs gleam under the dark coping of the basalt, and give us some clue as to the geological age of the eruptions.

The volcanic character of such a country is unmistakable. If we merely climb the steep side of Cave Hill above Belfast, and wander along the curved front of the cliff, we shall find scoriaceous rocks in plenty, sometimes compact, uniform, and black, sometimes with a delicate groundwork in which the crystals are just visible to the naked eye. In many cases the steam-vesicles are partly or wholly filled up with white minerals; these are hydrous silicates derived from the alteration of the felspars, and are occasionally accompanied by quartz, which was deposited during the same chemical changes. Often the cavity became lined at the outset with a green earthy layer, resulting from the attack of water upon the silicates of iron and magnesia, compounds of these materials being among the earliest minerals to decay. Within this green layer, the nest of clear and colourless silicates has been formed. Such a structure is called **amygdaloidal**, from the Greek word for an almond, the rock looking like a dark cake stuck full of little almonds. These *secondary minerals* in the steam-hollows often crystallise inwards in a delicate fibrous fashion, and their structures are well worth studying with a lens.



COLUMNAR AND MASSIVE LAVA-FLOWS
AT PLEASKIN HEAD, CO. ANTRIM.

PLATE VIII.] [*Photographed by* MR. R. WELCH.

In the cliffs of the north, towards the Giant's Causeway, the double structure of the lava-streams is magnificently displayed (Plate VIII). Tier upon tier of black-brown rocks are exposed on the storm-swept headlands, columnar structure standing out superbly in almost every alternate layer. The layer above each zone of columns is the upper and more irregular portion of the stream; and here and there some massive flows have escaped columnar division altogether. We have already seen (p. 173) how the admirably perfect "Giant's Causeway" is merely the basal part of a lava-stream, which is found in its entirety in the terraces of the cliff above. Red bands sometimes occur between the lava-flows, and are especially striking on the volcanic coast of Skye. These represent the oxidised surfaces of decay formed in the interval between one lava-flow and the next. Soils were produced by atmospheric action, and vegetation at last rose upon the consolidated lava. Leaves and twigs were washed into the little pools that accumulated in the hollows, and crusts of red and brown iron oxide were deposited in nodular masses upon their floors (see p. 142). In time all this was covered by another flow, and the nature of the leaves, thus remarkably preserved, has enabled geologists to fix the period at which these Irish volcanoes were in activity.

Similar leaf-beds occur in the west of Mull, as thin layers amid the frowning cliffs of basalt, and show that the great volcanoes of the Hebrides were also pouring out their lavas at the same time as their rivals in County Antrim. Indeed, at that period, later than the deposition of the Chalk, there must have lain "underneath the area of Britain a reservoir or series of reservoirs of lava, the united extent of which must have exceeded 40,000 square miles."[1]

Besides the andesites and basalts, County Antrim contains examples of almost every variety of rhyolite, and a whole broad hill north of the Tardree Mountain is coated with a lava-flow of obsidian, which is now breaking up into decaying boulders amid the peat-bogs.

The formation of the **lava-plateaux**, here and elsewhere, is fairly easy to understand. The tendency of long-continued eruptions is to fill up all the hollows of a country,

[1] A. Geikie, "The History of Volcanic Action during the Tertiary Period in the British Isles," *Trans. Roy. Soc. Edinburgh*, vol. xxxv, p. 72.

as we have seen in the case of the lavas of the Puy de Côme and the Louchadière. The fluid basalt imitates, as it were, an alluvial flat, and on this level floor, perhaps a century later, another flow accumulates. This may not occupy the whole width of the valley, but a third one may come down and fill it up completely. Meanwhile, neighbouring valleys have been similarly choked, and at last the ridges between them are buried by lavas piled to so high a level that they have been able to override the barriers. A long succession of events like these covers the whole country with an almost uniform surface of lava, above which a few scoria-cones, breached by the flows or thrown up later, rise picturesquely and indicate the actual vents.

These cones then become destroyed by denudation; again and again they have arisen during the long history of the plateau, to be washed down into level tuff-beds and to be buried by eruptions from some other source. A stratification is thus established in the volcanic series, which imitates the horizontality of marine deposits.

But, if we try to follow out one of the lava-streams over some long cliff-face, we shall find that it is not a broad sheet, flooding half a county from some continuous fissure in the crust, but that it terminates in a narrower edge on either side. The apparently uninterrupted stratum that attracts us at a distance is really built up of several flows;[1] these have run down side by side, but at different periods, the one making good the deficiencies of the other, and the whole series conspiring to level up the surface of the land.

The north-eastern counties of Ireland were formerly like those of south-east England, a country of rolling hills of chalk, with their upper slopes covered with short grass, and their hollows cumbered with flint-gravel, the product of their own decay. Through this upland, in what we call the Eocene period, the volcanic action broke; here and there a huge cone arose, rapidly piled upon the scorched and shattered Downs; but the ground, like that of Auvergne, yielded at several points at once, and flow after flow of andesite and basalt were poured forth from a number of small vents. The lower flanks of Etna at the present day show us somewhat similar features.

[1] See A. Geikie, work above quoted, p. 80.

The abundance of dykes in County Antrim points to this multitude of vents. These dykes are difficult to trace inland, owing to the grass and the bogland of the plateaux; but in quarries and along the shore they are conspicuous. Carrickfergus Castle, which rivals Caernarvon in its position as a stronghold of the sea, is built upon a weathered-out basaltic dyke, which is exposed for about a mile and runs out like a spur into the water.

Scrabo Hill, an isolated relic in the north of County Down, is a marvellous dissection of one of these Eocene volcanoes. Great quarries have been opened in the pink-brown sandstones which form so large a portion of the hill; and dark basaltic dykes can be seen running up across these artificial cliffs, and sending off sheet after sheet along the planes of bedding of the sediments. Nothing on the slopes of a modern volcano can be clearer than the sections thus revealed. The upper part of the hill is formed of sheets of lava, some of the dykes penetrating these also and reaching the present surface of the ground.

Carnmoney Hill, north of Belfast, contains the neck, conveniently quarried into, of another of the old scattered cones; this mass is oval in section, and about a third of a mile across. Naturally, this slowly cooled volcanic plug has became completely crystalline. At Carrick-a-rede, again, some miles east of the Causeway, there are extensive beds of volcanic tuff, and a well marked neck, which is exposed by the cutting of the sea. This vent was about 1000 feet in diameter, and is choked with "a coarse agglomerate, in which blocks and bombs of basalt, with pieces of chalk and flint, are stuck at all angles in a dull dirty-green granular tuff."[1] Another centre of eruption, conspicuous for miles around Ballymena, is the grand mass of Slemish, rising like a huge fortress, girt with cliffs, above the long curves of the basalt plateau. It may once have been surrounded by a cone of ash and tuff, culminating 1500 feet above the sea; but it now stands out as a denuded core, the one true mountain in the county. It is still suffering from attack, and the clouds gather first upon it when the moist wind blows from the great sea-inlets of the west.

Fair Head itself (Plate IV), one of the noblest promon-

[1] Geikie, work above quoted, p. 105.

tories of our islands, is an intrusive mass some 250 feet in thickness, banked up below by a talus of blocks as large as houses, and rising above in a sheer black wall of strikingly columnar structure. Its rugged back is worn out into hollows in which little lakes have gathered; and from its summit of 636 feet we see in the south the long dark plateau-edge, resting on white exposures of the buried Downs of Antrim.

The formation of plateaux by accumulated lava-streams is seen even better in the desolate north of Skye, where the landscape is one long series of platforms, piled upon one another, with brown columnar steps between them. Bog-myrtle, and Cotton-grass, and the pale stars of the Grass of Parnassus, grow upon these bleak wet uplands; while the air is always tinged with soft grey rain, and the smell of sodden oat-fields rises from the crofts along the hollows. In the shallow valleys the view is cut off by the basalt tables on either side; and it may be a walk of miles across the yielding bog before we can attain some watershed and look out on the Atlantic and the isles. It is hard at first to compare these brown-green watery uplands with the cleanly outlined and diagrammatic features that we left behind us in Auvergne.

The rain-swept volcanic isles of Scotland have, however, quite a literature of their own; and we shall return to them some day later to inspect their central rocks. Although they are among the most recent igneous masses in our islands, they have suffered even more than their contemporaries in County Antrim. The outlying lava-flows have thus been cut up into sea-stacks, showing, even in this detached condition, the terrace-structure of the plateaux.

When we search among the strata of earlier periods for relics of volcanic action, we find ample evidence that again and again in the history of any country molten rocks have reached the surface, and have profoundly affected the features of our present landscapes, by reason of their resistance to denudation. The long line of the Ochils, so conspicuous from Stirling, is the edge of an ancient plateau of brown and purple andesites, part of a volcanic mass 6500 feet in thickness, and extending over an area at least sixty miles in length.[1] The Castle at Edinburgh stands

[1] Sir A. Geikie, "Anniversary Address," *Quart. Journ. Geol. Soc.*, vol. xlviii (1892), *Proceedings*, p. 70.

upon a crag of basalt; while Arthur's Seat, the crowning glory of the city, is a black volcanic neck, surrounded by lavas and ash-beds, which give great variety to the surface. The grand wall of Salisbury Craigs is formed by an inclined intrusive sheet, which has notably baked the shaly beds beneath it.

Sir A. Geikie, in two comprehensive and finely illustrated volumes,[1] has given an account, rich in details, of the history of volcanic action in the British Isles. We need only in conclusion take our stand upon the narrow arêtes of Snowdon, and look round upon the peaks and ridges of North Wales. Scarcely one of these prominent masses is unconnected with lava-flows or intrusive igneous rocks. The Moelwyn range above Ffestiniog, the jagged summits of the Glyders, the smooth-backed Carnedds in the north, and the twin-peaks of Yr-Eifl in the west, have all been weathered-out from some of the oldest volcanoes of our isles. The great dome of Mynydd-mawr, quite near us, is a neck a mile in diameter, once filled with an almost glassy lava, which has now become pale and white and crystalline. The hollows of Snowdon itself are carved through tiers of rhyolitic flows and tuffs, which have been traversed by dykes of basalt. In the compact highly silicated rocks the microscope shows us perlitic structure; while spherulites, large and small, can easily be detected with the naked eye. In walking down the Pass of Llanberis, some of the *roches moutonnées* on the left are formed of the resisting basalt dykes; while above us on the right a bold columnar crag juts out from Esgair-felen, and sends down a loose talus to the road. Once this mass must have been black and glistening, like the obsidian cliff in Yellowstone Park; while above it and beneath it lay rhyolites of brilliant hues, pink and pale-yellow and white, with abundant layers of back glass. All have now undergone slow *secondary crystallisation*, through changes and earth-pressures which took place long subsequent to their consolidation; and they have become almost uniformly dull and grey. Quartz has been deposited in their cavities, and fills many of the fissures which have opened far across the hills. Many geysers and hot springs of the present time, aided by the minute water-plants that live in their basins, deposit silica as they flow; and thus the quartz-veins

[1] "Ancient Volcanoes of Great Britain" (1897).

of Snowdon probably represent the last stages of a long period of eruption. Even if we go back to the earliest strata of Britain, we can trace out the sites of old volcanoes; and the lavas, as well as the kind of action at the vent, appear to have been the same as those occurring at the present day. Just now, in the British Isles, we are in a period of quiet, such as that which prevailed through enormous ages between the deposition of our coal-beds and the upheaval of the chalk above the sea; but the far future may again rear cones and craters upon our smiling landscapes, and may bury deep in hot scoriæ and steaming lava the traces of our human enterprise.

CHAPTER VII

A GRANITE HIGHLAND

WHEN we have become accustomed to examining the products of volcanoes, we may take up again the lump of granite which we have laid aside since our earliest chapter. It contains well formed mica, and orthoclase felspar, with its simple twinning, and quartz acting as a sort of ground, set in between the other crystals. All these minerals may occur in rhyolite; we have seen that they all may be separated out during the cooling of that lava in the vent. In granite, moreover, they show no signs of rounding, nor is there a cement to bind them together; they seem to have grown in place successively, and not to have been brought together as sedimentary materials. In fact, we may reasonably suspect granite to be also an igneous rock.

Even though the crystals may be coarsely developed, the felspars becoming several inches long, this is merely an extension of the complete crystallisation which we have seen in the heart of massive dykes. And, when we study granite in the field, we shall hardly be surprised at any degree of coarseness in its texture—the masses we deal with are so enormous, and their rate of cooling must necessarily have been so slow.

Many of our British highlands are built of granite, and there we may see it, as a rock always should be seen, in its relation to the other masses of the earth's crust. The granite area will be an open moorland, such as will rejoice the pedestrian; and a few well-marked summits rise above it here and there.

Though the whole area is high, there are few features of especial grandeur. The hills are mostly rounded, with long curving sides descending unbroken to the valleys (see background of Plate IX). Here and there a cirque has been cut out on the flank of one of these great domes; and the cliff, viewed from the side, may stand out boldly against the sky. Curious groups of rocks, almost like ruined citadels, rise

from the higher slopes of many of the hills; and long taluses stream down from these, until they are swallowed in the bogs that fill the hollows. Grass and fern and heather clothe all the drier portions of the mountains; and in August the landscape for miles is a stretch of glorious purple. Small plantations of Scotch firs have been made, which climb from the valleys towards many of the barren ridges; but these wide mountain-curves give little shelter, and sometimes the path of a storm-gust is marked by the red stems heaped together in a shattered band across the woodland.

If we climb along the ridge between two valleys, we shall see a striking similarity on either hand. The spur on which we stand is like the back of a huge elephant, broad and rounded, with hardly a rock-surface to be seen. Down below, the streams have exposed the granite along certain steeply descending grooves; but the valley-floors are covered with boggy alluvial flats, in which the main rivers wander in frequent curves.

As we rise higher, we see that the hill in front of us assumes a nobler aspect. Its true form was hidden by the great uniform masses of its lower slopes; but now bare walls of granite can be seen along its steeper crest, and even the slopes themselves are often too abrupt for taluses. Grass ceases to cover the huge slabs of solid rock, which weather out like grey inclined planes, continuing upward at the same angle as the valley-side below. There may be no true peak above the valley-head, yet this great dome in front of us has a grandeur of its own; and it proves after all no easy climb to reach the grassy summit.

Let us rest on the edge of one of the broad exposed surfaces, some 2000 feet above the sea (Plate IX). The grass and moss are endeavouring to get a hold on it, but their little tufts are easily dislodged. The rock weathers somewhat evenly, with shallow pits in its surface where the rain-storms have found weak points to begin on. If we look along the plane of the slab, we shall see how there are some parts rising higher than others, ready to be flaked off along joints parallel to their surface. In fact, the mass has a **tabular jointing**, dividing it into great gently curving slabs; and the forms of the slopes are largely determined by the angles at which these main joints lie.

It is difficult to cross so uniform a sheet of rock; we

GRANITE EXPOSED ON SLOPE ABOVE THE KILKEEL RIVER, MOURNE MOUNTAINS, CO. DOWN, SHOWING CHARACTERISTIC MODE OF WEATHERING.

PLATE IX.] [*Photographed by* Mr. R. WELCH.

may even dislodge some hesitating flake and send it down over the slope, before its time, into the valley. The weather has roughened the rock by affecting the minerals unequally, and the quartz stands out in little sparkling grains, while the worn-down felspathic areas may be partly overgrown by lichens. This roughness is noticeable even if we get our fingers into one of the tabular joints, and feel the under-surface of a slab. The fairly rapid destruction of the felspars soon widens the joint; the mica and quartz become washed out as sand; iron rust forms and stains the decaying surface; and finally the brown and crumbling mass slides down the mountain-side, breaking up as it goes and scattering its dust throughout the heather.

Sometimes these tabular joints lie horizontally, and give a flat-topped or gently swelling summit to the hill. Beyond us is a cliff in which there is all the appearance of stratification; and we can see how another set of joints, unnoticed by us before, has determined the exposed and vertical surface of the rock. Two such sets of joints, indeed, occur, roughly perpendicular to the first series and to one another; and each set is in turn brought into play, according as the local agents of denudation work most persistently in one direction or in another.

The uniformity of structure of the granite mass has checked the formation of conspicuous peaks; but here and there, as we noticed from afar, a few rocks rise above the general curves of the long moorland. These masses are called *tors* in Devonshire, and are easily seen to be in all stages of decay. The tabular joints control the outlines of some, and the blocks fall away from beneath certain of the layers, leaving ledges projecting out above our heads. In other cases the three main sets of joint-planes have divided the mass into fairly regular blocks, almost like the squared stones of buildings; and the weather has widened some of the vertical cracks and has produced deep gullies through the tor. Hence the castellated effect of many of these masses at a distance. But every stone has become rounded on its edges, and crusts of decaying material cover the surfaces and crumble away when they are struck. Gradually the well-formed block, bounded by sharp joint-surfaces, becomes reduced to a boulder, unstably perched upon the rock below. A little wedging of frost, a little

further crumbling of its lower surfaces, and it falls readily upon the talus, to be slowly buried there in the grass. All round the present tors on Dartmoor, the taluses are far more remarkable than the upstanding rocks. They stretch away in long concave curves from these diminished crags, these relics of old peaks, and thus encumber miles of moorland. The former greatness of what we now call tors is to be seen in the blocks which lie everywhere strewn amid the heather.

All stages can be traced between the typical tor, standing up so quaintly on the summit of its talus-cone, and the huge rock-domes which we have here before us on our highland. When once cirques begin to be formed in the mountains, the mass between their retreating curves is doomed. Gradually the convex table of the summit is reduced to a flat-topped rock, girt about with cliffs; at its base the taluses stream down in all directions, the great boulders being heaped on one another as if shattered by the catastrophe of a moment; and at last even the table becomes worn out into pinnacles, which go down one by one into the encroaching hollows of the combes. The scene reminds one of the decay of some great empire, as the changes of the times draw away the states on all sides, leaving the centre of power still more prominent, by reason of its very isolation.

In Cornwall, some of the rock-pillars that are left behind seem at first as if built by human agency, rather than worn out of a once solid mass. In the Mourne Mountains, again, there is a group of pinnacles (fig. 19) fantastically flanking a little cañon, beyond which there lies a circular hollow set about with similar columns. We seem to see the vestibule and the central hall of some old temple; and it is hardly strange that legends should still hang round these wind-swept recesses of the rocks.

In all such cases it is the horizontal jointing that gives the effect of masonry; but this structure is not aided by any difference in the texture of the layers, which might cause the hillside to weather out into steps and terraces. All round us the rock slips evenly away, boulder by boulder, slab by slab, and these great uniform slopes are the result.

As we cross a smooth exposure of the granite, we see little dykes and veins, usually of more finely grained material, cutting across the main mass of the rock. Some of these even cross one another; and often the fissure that has ad-

mitted the more recent of two veins has been accompanied by a movement, which has shifted the broken edges of the earlier vein, until they are no longer opposite to one another. We may note that these dykes consist also of granite, which is often very compact in texture; and even in them the crystallisation can sometimes be seen to be

FIG. 19.—GRANITE PINNACLES, SOURCE OF THE ANNALONG RIVER, MOURNE MOUNTAINS.

(*Photographed by Mr. R. Welch.*)

coarser in the interior of the dyke and distinctly more delicate on its margins.

We are evidently in the presence of an igneous mass that has cracked open more than once since its consolidation. Material, still molten, was always at hand to ooze up from below and to fill up the fissures as fast as they were made. But the conditions of cooling were slow even in

these veins, since they have become completely, though often minutely, crystalline. The lower blocks of the consolidated granite may have been again and again absorbed into the liquid mass below, before the whole finally became solid. A subterranean reservoir may have existed, comparable to the lava-lake of Kilauea (p. 156), which now eats away, now reconstructs its walls; and in time the heat diminished, allowing the whole contents to crystallise, under conditions of far higher pressure than are experienced by any lava near the surface.

On many of our slabs of granite we see porphyritic felspar crystals, which must have developed previously to the finer material of the ground. These long orthoclase crystals are especially frequent in the granites of Devon and Cornwall, and the shorter pink crystals of the rock of Shap in Westmoreland have made it famous as an ornamental stone. Do they represent a period of greater earth-pressure and still slower cooling, when the rock began to crystallise on a grander scale? Was the mass then remelted, these large felspars being left to tell the tale of its first and unsuccessful efforts? These are some of the questions which arise when we try to conceive the operations that take place in a deep-seated caldron of molten rock. The abundant development of quartz is probably connected with the imprisonment of water under pressure; but further experiments on its artificial production are required to elucidate this point. Now and then we can trace, in veins and knots of deposited material, the course of hot liquids and vapours which subsequently passed through the rock; the older minerals have been deprived of some of their constituents, and new ones have arisen from the interaction of the invading substances and the granite. In this way minerals containing fluorine often arise, such as Topaz and Fluorspar; and black hard radiating rods of Tourmaline, a complex silicate and borate, grow out from centres of decay and spread through the rock like a disease. During the destruction of former silicates, silica is often set free, which crystallises as additional, or, as we say, "secondary" quartz. On Dartmoor whole rock-masses occur converted thus into tourmaline and quartz. In Cornwall, again, tourmaline is commonly formed, apparently by the action of boric acid vapours, on the sides of the granite veins; and, in the little inlet of Nanjisal, near the

Land's End, an altered granite occurs, in which the red porphyritic felspars are reduced to mere shells, their excavated interiors being partially or wholly filled up again by secondary quartz; while the more finely-grained ground is replaced by a mass of delicate tourmaline needles, set in granular lumps of quartz. The whole of this ground is of secondary origin, the former crystals of quartz and felspar and mica having been attacked, and part of their constituents having been used up again during this thorough process of reconstruction.

This shows how profound mineral changes may go on even in deep-seated and apparently protected masses. Minerals are deposited around the fumaroles in volcanic craters, where the vapours escape from the interior of the earth; but the chemical action of these gases will be much more extensive when influenced by the high temperatures and pressures in the interior of the crust. Whether the temperature is sufficient to keep them in the gaseous condition, despite the pressure, or whether the pressure condenses them into liquids, they will permeate the heated rock-masses and carry on a series of "mineralisations." In the short time at our disposal for the performance of a laboratory-experiment, it is impossible to imitate all these results of prolonged natural action; but many rock-forming minerals have now been artificially reproduced, particularly by a brilliant group of chemists and mineralogists in France, stimulated by the work of MM. Fouqué and Lévy.

There can be no doubt, however, that the principal minerals in our granite, and the structures of the mass, from the porphyritic crystals to the shrinkage-joints, are due to its consolidation from a state of fusion. The study of a series of rhyolites will show us how it is no step, but merely a continuous passage, from the most "stony" of these rocks to the fine-grained veins of granite; and from these we can pass easily to the most coarsely developed masses. It is natural, then, to conclude that in our granite highland we have the weathered-out contents of a caldron which once underlay a volcano or a series of volcanoes. These volcanoes would have erupted rhyolites; and the extinction of the area would have been due to the consolidation of the contents of the caldron by loss of water or by diminution of the heat supplied to it.

Many such caldrons must exist, however, without their molten matter attaining the surface of the ground; and it is difficult in any case to trace a connexion between the surface-products of a volcano and its highly crystalline basis. The cones and lava-flows must be swept away by denudation before we can get at the underlying rocks; and it is only in rare cases that some deep valley, or the borings of a mine, will reveal to us the two classes of products in their true relations to one another.

Occasionally the huge central neck of some old volcano will serve us almost as well. Professor Judd[1] has again and again emphasised the connexion between glassy and partly glassy lavas and the most crystalline central masses in the complex and denuded volcanoes of Mull and Skye. Messrs. Hague and Iddings[2] have similarly shown the lavas and completely crystalline rocks of Washoe in Nevada to be a continuous series, and have supported their evidence by a series of chemical analyses. Even the great majority of Continental observers, who felt that such a connexion was not established in their own countries, have now accepted the view that highly crystalline granitic rocks may be forming at the present day beneath our feet. Modern examples are difficult to get at—that is all. In the Hebrides, however, the wild west showers and the driving winds of the Atlantic have cut down into the central igneous masses, and have exposed coarsely crystalline rocks of a comparatively recent geological age.

If the broad moorland on which we wander is a true igneous mass, surely it must have produced, like a dyke, some effect upon the rocks which border on it. Let us cross the watershed, and descend from the high tors and towers, until we meet with some material different from the granite.

A few miles down the valley that we have selected, its walls become scarred with a series of ridges of dark rock, which run down parallel to one another, projecting from the grassy slope. They are occasionally curved and folded, and present all the appearance of uptilted strata.

[1] "The Secondary Rocks of Scotland," *Quart. Journ. Geol. Soc.*, vol. xxx p. 276; "Volcanoes," p. 142; &c.

[2] "On the Development of Crystallisation in the Igneous Rocks of Washoe, Nevada," *Bulletin U. S. Geol. Survey*, No. 17 (1885).

Hard by, there is a large quarry, opened to obtain the granite; and at the lower end of it the dark rock appears as a projecting bluff, cut round and neglected by the workmen. The contrast of the two rocks is striking; and we have here come to the edge of the granite mass.

A few moments' inspection shows us that the pale pink and orange granite has almost wrapped round the darker rock; a dyke of granite has run out at the junction, and can be seen wandering away up the quarry-face. The dark rock is shaly, but its delicate planes of division are covered with gleaming plates of mica; and fine threads and sheets of what appears to be quartz occur freely in between the layers.

Some of these filmy sheets actually are composed of quartz; they agree in character with the deposits in many of the cracks that we observed high up amid the granite. But others are seen on close inspection to contain felspar; here and there a mica flake occurs; and these delicate bands are really offshoots from the granite.

At another point small veins run off distinctly from the main mass across the bedding of the shaly rock, thus imitating the larger dyke. There can be no doubt as to the character of the junction which we see here exposed. The granite is, as we say, *intrusive* in its stratified surroundings.

If we now climb the slope, we shall be able to trace the line of junction, bending now this way, now that, and shall find ample evidence of its irregular character. More than this, the granite near its margin contains numerous dark flecks and patches, and these prove to be pieces of its neighbour, which have actually become picked off and partly melted. The delicate intrusions at the junction down in the quarry have prepared us for this intermingling of the rocks; and even the great projecting bluff is, as we saw, almost completely surrounded by the granite.

Sometimes the intrusion of veins along the bedding-planes of the shale has produced a rock composed of alternating layers of dark micaceous shale and pale pink granite. This would be a difficult material to understand if we saw merely a loose specimen of it, instead of collecting it for ourselves. The whole hillside now above us gives a wonderful picture of the attack of the molten rock, when

far beneath the surface of the ground, upon the older masses into which it flowed.

If this seems simple to understand, when we see the network of veins before us in the field, and when we consider its similarity to what is revealed by the denudation of a volcanic centre, yet this version of the origin of granite is really very modern. James Hutton, the great Scotch geologist, was the first to prove, by producing similar evidence, that granite was an igneous rock, his observations being made in Glen Tilt in 1785. Even in our own day, distinguished authors have asserted that rocks of granitic structure could be formed as deposits from hot solutions, perhaps at the bottom of the sea. A kind of solution there may be, when we consider the water that permeates the mass, even when at its greatest heat; but of the former molten condition of the rock there can be no reasonable doubt.

The study of the fragments of other rocks picked up and surrounded by granite has been carried on microscopically in several countries; and we find that some constituents of the included rock may become melted to a glass, while others are left but little injured. Ultimately the latter minerals remain alone, scattered through the granite, all trace of their mode of origin having disappeared. It is clear that this selection of minerals, dependent on the greater fusibility of some of them, may provide the granite, when it consolidates, with constituents of a very puzzling character. The porphyritic crystals of lavas have no doubt often been derived from similar foreign sources (p. 168); and it is convenient to speak of all such objects, when their origin can be traced, as **derived crystals**.

The dark rock in contact with the granite now demands attention. It has some characters of a shale, as we have already noted, but is remarkably crystalline. Some layers are crowded with distinct flakes of mica; in others dark specks and rods stand out in a fine grey micaceous ground. We must follow this mass step by step down the valley.

As we recede from the granite, the amount of conspicuous crystallisation diminishes, and the whole rock is duller and more compact. At last, perhaps a mile away, we find it as an ordinary shale, and we may be so fortunate

as to detect traces of marine animals in it. At one time, then, these muddy strata were deposited in the sea. They have been uptilted, and the granite has flowed into them; is it not, then, likely that the igneous rock, with its slow cooling, and the escape of liquids and vapours from it, has produced the crystalline condition of the mass along the junction?

We use the term *metamorphism* to express the production of such extensive changes, of which heat and pressure, singly or both together, have been the causes; and we say that such changes as we now are studying result from **contact-metamorphism**. Limestones become crystalline when in contact with great igneous masses, silicates rich in calcium becoming developed in them, often by an interchange between their constituents and those of the invading rock.[1] Sandstones become hardened and compacted, and any fragments of felspar occurring in them become more or less melted and form a glass between the grains of quartz. Clays and shales become baked into a dark flinty condition, some of the particles actually melting; here, again, any felspathic grains will aid the process, while chemical combinations become set up which result in the formation of new crystallised minerals in the mass.

Two of the commonest minerals which arise from the contact-metamorphism of mixed materials, such as impure clays, are a pale mica, containing a good deal of water in its composition, and pink-red or pink-brown *garnets*. The garnet series consists of silicates of various metals, the latter replacing one another without altering the type of crystallisation. Garnets belong to the cubic system, and commonly appear as somewhat spherical bodies on the fracture of the rock containing them. In reality, the most usual form has twelve faces, its high symmetry giving it a granular aspect when it is developed on a small scale. The reddish garnet so frequently occurring is called *Almandine*, and is a silicate of aluminium and iron; it easily scratches our knife-blade, and, from its colour, can be picked out readily by the eye.

Another substance, however, has assembled to form the

[1] See, for instance, Johnston-Lavis and Gregory, "On Eozoonal Structure of the Ejected Blocks of Monte Somma," *Trans. Roy. Dublin Soc.*, ser. 2, vol. v (1894), p. 259.

dark spots and patches. Some of these are composed of materials that could not arrange themselves sufficiently well to form recognisable minerals. But others have reached the stage of fairly outlined rods, like little pieces of slate-pencil. These have been shown by chemists to be *Andalusite*, one of the forms adopted by crystallised aluminium silicate. This is precisely the mineral that one might expect to arise from the prolonged heating and compression of a clay, seeing that clays are almost entirely made of aluminium silicate combined with water. Andalusite often developes in radial bunches, and sometimes gets rid of the impurities which give it its dull colour; it then appears as sharp-edged four-sided little rods, lying, like wooden matches, in the groundwork of compacted clay.

It is pleasant to observe in microscopic sections of the products of contact-metamorphism how large a part is played in the resulting crystals by the impurities caught up in them. The crystallising matter collects round a number of stolid unaffected particles of the original rock, and tries, as it were, to elbow its way in between them; finally something like a crystal is built up, the faces being in reality very ill defined, and the great bulk of it being formed of matter which could not be thrust out from it.

The neat little match-like crystals of andalusite which occasionally occur, as in the altered shales of Skiddaw, have succeeded in arranging the impurities within themselves into two sheets, connecting the opposite pairs of long edges of each rod, and also into the form of five columns, one running down the central line of the rod and one down each long edge. The result, when the crystal is broken across, is that a black cross appears, with patches at its ends and at the centre; and this variety of andalusite has consequently been named *Chiastolite*, or "cross-stone."

Metamorphism along a plane of contact is naturally a long process, and minerals are developed and succeed one another just as they do during the slow crystallisation of an igneous rock. Thus Miss Gardiner[1] noticed that, in the zone of alteration round a granite in the south of Scotland, the garnets appeared first, as was shown by the fact that they included none of the other products of metamorphism. The

[1] "Contact Alteration near New Galloway," *Quart. Journ. Geol. Soc.*, vol. xlvi (1890), p. 579.

chiastolite, however, included the garnets; and the micas were formed against and bent round both these minerals.

A large number of the little irregular black spots that occur in altered shales are really due to mica, which can be traced in all stages of development. After all, in the great majority of these rocks, as we walk across them in the field, mica is by far the most striking feature.

Messrs. Harker and Marr[1] have shown how about thirty species of minerals have been developed in various rocks round the granite of Shap in Westmoreland. In many cases the molten mass acted upon older igneous rocks; but at least twenty-one of the mineral species arose in the adjacent shales and limestones. The formation of both orthoclase and plagioclase felspars in these sedimentary rocks is the most noteworthy point in the results obtained.

The zone of alteration round the Shap mass is about 1200 to 1300 yards wide, the granite, as exposed at the surface, having a diameter of about 2500 yards. In most cases, the constituents of the rocks close to the contact have become entirely rearranged. The minerals that had already been formed in the adjacent igneous rocks by processes of decay, such as carbonates and hydrous silicates, were the first to suffer from the metamorphic action. The authors believe that no transference of materials from one rock to another has occurred in this case, and that the new crystals, even the wonderful assemblage of pyroxenes, and amphiboles, and garnets rich in lime, in the altered limestones, have arisen by the creeping together of materials already present in the sedimentary rock.[2] M. Lévy, on the other hand, and French workers in general, lay stress on the mingling of constituents that may go on in such cases, and support their arguments by many excellent examples.

We have now looked into the past history of our granite highland, and have pictured it as a molten mass, working its

[1] "The Shap Granite, and the associated Igneous and Metamorphic Rocks," *Quart. Journ. Geol. Soc.*, vol. xlvii (1891), pp. 292–325; and "Supplementary Notes on the Metamorphic Rocks around the Shap Granite," *ibid.*, vol. xlix, p. 359.

[2] The literature regarding the products of contact-metamorphism is admirably summarised by F. Zirkel, "Lehrbuch der Petrographie," 2nd edition, Band ii, p. 82, &c. For British examples, see J. J. H. Teall, "British Petrography," p. 373.

way into the surrounding strata and imprisoned deeply underground. At present its denudation and decay offer us many interesting features, especially since the sedimentary rocks, with which we are already familiar, are so largely derived from the decomposition of igneous ones.

When examining the tabular joints on the shelving surface of the mountain, we saw how the rock was going to pieces through the attacks of the weather upon its constituents. Analyses show that the soda is carried away most rapidly from a decomposing granite, and the potash far more slowly, both these substances being extracted from the felspars. If lime is present, it is carried off at least as quickly as the soda. In any case, part of the attacking water becomes combined with some of the constituents of the granite, and the proportions of silica, alumina, and iron oxide remain about the same, the silica generally increasing slightly. But a great physical change accompanies these chemical ones; the surfaces of the felspars become coated with fine kaolin dust, and at last those developed porphyritically can be lifted out of the rock-mass. Their cleavage-surfaces similarly become powdery, and the crystals themselves break easily into little blocks. The micas, especially the biotites, take up water and alter into still softer products, such as chlorites. Any hornblende that may be present similarly passes into soft green powdery products. A certain amount of iron oxide is set free, which takes up water and forms brown streaks and films; while the smaller felspars pass entirely into powdery kaolin, like flour. The stubborn quartz, now dusted over with kaolin, rolls out loose into the *débris* of the slope. Its original granular form fits it admirably for further wanderings, and it already resembles grains of sand.

The great streams of solid matter washed down from the decaying cliffs can be appreciated when we look up at them from the floor of our valley. The little torrent in the hollow is busy sifting them out, and already we have banks of sand amid the alluvium, from which the fine clay has been removed. Much of this sand, however, when we run it through our fingers, is composed of little lumps of granite, which are ready to be further broken down, but which still contain all the constituent minerals associated together.

The finer matter, washed away and laid down in the alluvial levels a few miles lower down our valley, is divided into particles consisting of separate minerals, the bulk being kaolin with embedded grains of sand. At this point commercial companies have set up works for its further artificial subdivision, and the pure white kaolin is washed out into tanks and finally sent off to the Potteries as *china-clay*. The natural agents would have finally sorted out the materials on the sea-coast (p. 100); but by that time other ingredients would have got in, and the kaolin would be no longer pure. It is coloured on the shore by iron oxide, by iron sulphide, by decaying animal and vegetable matter; it thus becomes merely common clay.

Here then we are at the source of our sands and clays, two great groups of sedimentary rocks. We can, in fact, trace them back to igneous masses. Even the salts of lime that are carried away from our highland in solution go to furnish the sea with calcium sulphate and calcium carbonate, from which the lime is again extracted by organisms for the construction of the calcium carbonate of their shells and skeletons. Thus granitic rocks also help to form the great beds of limestone, the shell-banks and the coral-reefs, which constitute our third main group of sedimentary deposits.

When we picked up our granite specimen at the outset of this chapter, we compared its constituents with those of rhyolite. A typical analysis of rhyolite-obsidian, the most glassy rock of this series, has been given on p. 166. If we powder up a good lump of granite, so as to get all its constituents well mixed in average proportions, we shall find that its analysis agrees well with that of rhyolite. From the point of view of our chemist, the two rocks would be practically identical; the difference is one of structure, arising from different conditions of temperature and pressure during consolidation; and thus every variety of rhyolite can be paralleled in chemical composition by a possible variety of granite, or *vice versâ*.

Let us take two granites from the British Isles as our examples, expressing the constituents, as is usual, in the form of oxides. The first one consists of quartz, orthoclase, albite, muscovite, and a little biotite, and is a typical "white granite"; the second is the famous "red granite" so largely

used for ornamental building, and contains similar constituents to the other, muscovite being, however, absent.

	I. Average of eleven analyses of Granite of the Leinster Chain, Ireland. (Dr. S. Haughton.)	II. Granite of Peterhead, near Aberdeen. (J. A. Phillips.)
Silica	72.07	73.70
Alumina	14.81	14.44
Iron oxide	2.25	1.92
Lime	1.63	1.08
Magnesia	0.33	trace
Soda	2.79	4.21
Potash	5.11	4.43
Loss on ignition	1.09	.61
Total	100.08	100.39

The rocks commonly called "granite" in the building-trade vary, however, very widely in mineral constitution, though they agree fairly in structure; and they are known to geologists under distinct names. It is highly desirable that architects and others should recognise the differences between them, since the degree to which they may be attacked by weather, as well as the convenience with which they can be worked, depends largely upon their mineral constitution.

If our typical granites, as above analysed, correspond to rhyolites—if, indeed, a granite caldron would clearly erupt rhyolite at the surface—are there no deep-seated masses corresponding to the other types of lava? As a matter of fact, although the word "granite" is familiar to all of us, it covers only one out of four great groups of completely crystalline igneous rocks. These are:—

1. **Granite.**—This rock contains from 65 to 75 per cent. of silica, corresponding to rhyolite in composition. Its characters have been sufficiently described above, with the exception of its specific gravity. This is higher than that of rhyolite, owing to the complete crystallisation, but lower than that of other rocks of similar structure, owing to the small amount of heavy oxides that granite contains. The specific gravity is thus about 2.65.

2. **Syenite.**—Here we have only some 60 to 65 per cent. of silica, with potash, as in granite, in excess of soda. The name is from Syene, the modern Assouan; but the rock of that area, extensively used by the ancient Egyptians, is properly a Hornblende-granite in our modern classification. Caesalpinus,[1] writing at the end of the sixteenth century, uses "*Syenites*" and "red granite" (*granitum rubrum*) as terms having the same meaning; but Syenite is now restricted to a rock practically free from quartz. Orthoclase felspar, and an amphibole, or a pyroxene, or a mica, are the important constituents. The rock is a granite without sufficient silica to form quartz, and thus consists typically of two minerals only. It is often red, owing to the colour of the prevalent crystals of orthoclase. Its specific gravity is about 2.75. It is obvious that this is the deep-seated representative of trachyte.

3. **Diorite.**—The silica here runs from 70 to 55 per cent., with soda in greater amount than potash. The name is from διορίζω, "I distinguish," because of the clearness with which the two main constituents stand out from one another. Plagioclase felspar (albite, or oligoclase, or even labradorite) takes the position that is occupied by orthoclase in the syenites. In some cases the silica is sufficient to form quartz, and the rock is called a *Quartz-Diorite*. The quartz-diorites are probably quite as abundant on the globe as the true granites. Typical diorites consist of oligoclase and hornblende, or mica, or pyroxene; those varieties with least silica contain more lime than the others, and the crystals in these are often labradorite and augite. The pyroxenic varieties are generally called *Gabbros*. The colour of the rock is usually white spotted with black. The specific gravity is about 2.80 in those varieties rich in silica, and 2.95 in those rich in lime, magnesia, and iron oxides. The diorites thus cover in their characters the same range as the great group of andesites.

4. **Olivine-Gabbro.**—Here the silica-percentage is from 55 to 45, and the heavy oxides are of increased importance. The name Gabbro is derived from that of a Tuscan village, the rock being spoken of in the last century as "*granito di Gabbro.*" Gabbro without olivine consists of a plagioclase and a pyroxene, and might come with us under the head of "pyroxene-diorite." Olivine-Gabbro contains a

[1] "De Metallicis," edition of 1602, p. 94.

plagioclase (labradorite or anorthite), a pyroxene (or rarely hornblende or biotite), olivine, and magnetite. The olivine marks the decrease in silica that has occurred, while the iron oxides have been able to crystallise out abundantly, instead of being worked up into silicates. They are usually associated with oxide of titanium, giving rise to titaniferous iron ores. The rock is darker in colour than common diorite, and is often blue-black through the abundance of pyroxene or amphibole, and through the fact that the felspars have become dulled and grey by internal chemical alterations. The large crystals of pyroxene in coarse varieties of the rock give a somewhat metallic lustre to certain portions. The specific gravity is about 2.90 to 3.00. The mass is commonly very tough and difficult to break, especially where the felspars are altered into new lime-silicates and where the pyroxenic constituent is abundant. Clearly olivine-gabbro is merely the completely crystalline representative of common basalt.

Hence, with the knowledge that these crystalline types of rock exist, we may enlarge and modify our classification of igneous rocks (p. 171) so as to include them. If we take the completely crystalline types as the bases of four rock-groups, we may use the minerals developed in them to guide us in our arrangement; this is a character that we could not previously employ when we were dealing with only partly crystalline materials.

SUMMARY OF IGNEOUS ROCKS.

Principal Mineral Constituents.	Name and approximate Specific Gravity.	Approximate Percentage of Silica.	Glassy representative and its Specific Gravity. (See also Table on p. 171.)
Quartz, Orthoclase, and Muscovite (or Biotite, or Hornblende).	**Granite** 2.65	70	**Rhyolite-glass** 2.30
Orthoclase and Hornblende (or Biotite, or Soda-pyroxene).	**Syenite** 2.75	65	**Trachyte-glass** 2.40

SUMMARY OF IGNEOUS ROCKS—*continued.*

Principal Mineral Constituents.	Name and Approximate Specific Gravity.	Approximate Percentage of Silica.	Glassy representative and its Specific Gravity. (See also Table on p. 171.)
Oligoclase (or Albite) and Hornblende (or Pyroxene, or Biotite); often Quartz.	**Diorite** (often **Quartz-Diorite**) Type rich in silica. 2.85	65	**Andesite-glass** Type rich in silica. 2.50
Labradorite, Augite (or Hornblende, or Rhombic Pyroxene), and Magnetite.	**Diorite** and **Gabbro** Type poor in silica. 2.90	55	**Andesite-glass** Type poor in silica. 2.65
Labradorite (or Anorthite), Augite, Olivine, and Magnetite.	**Olivine-Gabbro** 3.0	50	**Basalt-glass** 2.75

In all these types, the specific gravity usually becomes lower on the alteration of the rock, owing to the introduction of water and the formation of hydrous silicates, together with the removal of some of the heavy oxides in soluble combination.

Suppose, now, that we bring home three specimens of distinctly crystalline character, collected in the field, and that we wish to assign to them distinctive names. The first, for example, is made of orthoclase felspar and augite, with a specific gravity of 2.77. This may obviously be called an "Augite-Syenite."

The second consists of quartz, a plagioclase felspar, biotite, and pink garnet; its specific gravity is 2.90, being no doubt raised by the presence of the heavy garnets. This rock is evidently a "Quartz-Diorite with garnet."

The third specimen consists of a dull white plagioclase, augite altering into somewhat fibrous hornblende, a few dark soft lumps, which may be decomposed olivine, several chloritic areas, and conspicuous and lustrous patches of magnetite. The constituents in this rock are difficult to determine, and

we may be especially doubtful as to the former presence of olivine. The chlorite may have arisen from the decay of the hornblende, or from biotite, and the whole mass has evidently been extensively altered. We must place it as a possible Diorite or Olivine-Gabbro. A convenient field-name for all decomposed crystalline rocks of this type, poor in silica, with greenish alteration-products, is **Diabase**, an old term revived in this sense by Hausmann some fifty years ago.

For granites we may go to the long slopes and castellated tors of Dartmoor; or away west to the barren Cornish uplands; or to the great chain of Leinster, which is some sixty miles in length, and from 1500 to 3000 feet above the sea. In Scotland, from Perth northwards, there are numerous wide bosses of ancient date; but none are more interesting than the Red Hills of Skye, which are among the more recent igneous masses of the British Isles. The granite is here somewhat minutely crystalline, and probably it is only the upper part of a great intrusive mass. But its dome-like outlines are characteristic, as also are the broad enveloping taluses which flank these isolated hills. Far away, from the rugged shore of Balmacarra, the huge curved back of Beinn na Cailleach of Broadford can be seen against the sunset, with its sea-front scarred and carved into one steep cliff. Beyond it is the bold smooth cone of Glamaig, with Marsco, almost as simple in its outline, rising in the midst of gloomier and serrated hills. When we actually walk up the glen beneath these pink-red masses, we are apt to underestimate their height; already we see how weathering is wearing away the relics of a crag on Marsco, and is converting a mountain-peak into a round-backed granite moorland.

The former dignity of most of our granite ridges has thus been lost to us; but the Mourne Mountains in County Down in Ireland preserve a remarkable degree of steepness. Here, again, it is the massiveness of the scenery that attracts us, rather than any special detail; but the valleys are still of bold proportions, and deepen rapidly as we descend from their heads towards the sea. We view the open water from between two steep walls, where slabs of granite are exposed amid an expanse of heather; and above us the rock looms up into wild tors, which send down blocks for some 2000 feet into the hollows. If we stand upon one of these silent crests, we may see the western masses like huge grey walls

in the haze of a summer afternoon. Scarcely a break or ledge is now discernible, except where the white water of some mountain-lake seems to float like a cloud in the great gloom.

The date at which the Mourne granite intruded into the shales and sandy strata which surround it is probably, like that of the Skye masses, comparatively recent; but even later granite ridges are observable in the Alps, and will be inspected by us in a subsequent chapter.

Granites tend to graduate into quartz-diorites, even in the same rock-mass; but the diorites rich in silica produce similar scenic features to those of granite areas. The "granite" of Beinn Cruachan above Loch Awe, in Argyll, is largely a quartz-diorite; and this great mass, 3600 feet above the sea, has some twelve broad valleys carved down in it. The bare rock shows itself in a few cliff-ledges and towards the long ridge of the summit; but for the most part the hollows have smoothly curving slopes and floors, covered with grass or brown stretches of mountain-bog.

Syenites are decidedly rare rocks, one of the few British examples being that of Groby, at the south end of Charnwood Forest in Leicestershire. The quarries cut in this district are of great size, and the stone is broken up and sifted by machinery through coarse sieves made of iron plates perforated with circular holes. It is then exported throughout all eastern England for road-metal, and promises to become one of the best known of our igneous rocks. Its delicate pink-purple and greenish tints make it easily recognisable in the wayside stone-heaps.

The diorites poor in silica are exceedingly common rocks, especially in the form of dykes. These rocks form the bulk of the "Greenstones" of older authors, although this term became at one time carelessly applied to practically any igneous rock that could not be called a granite. A bold mass of diorite forms Hanter Hill on the border of Herefordshire and Radnorshire; and Stanner Hill, on the other side of the Kington road, is a similar dark rock penetrated by fine-grained granite. The glaciated ridge of Mynydd-y-Gader, which forms a fine foot-hill to the wall of Cader Idris, consists also of a coarse augite-diorite. Dykes and intrusive sheets of this rock run along the whole of the middle ledges of the mountain, penetrating the tuffs and altered shales.

These dark masses, in which the augite stands out conspicuously on weathering, form a striking contrast to the pale grey rhyolites and to the andesites rich in silica, which form the great cliff of Cader Idris, and which also emerge in a long band farther north.

Carlingford Mountain, on the south side of the sea-inlet which reaches up to Newry in County Down, is composed of a dark pyroxene-diorite, the typical "gabbro" of most authors (see p. 205). The high ridge has weathered with a serrated outline, and great bosses and steps of rock occur all across the upper slopes. The joint-surfaces are less regular than those of granite, and a corresponding irregularity of surface is the result. As a picturesque mass, Carlingford Mountain is far more impressive than the whole group of the Mournes across the water; and this nobly broken character is found to be characteristic of all high areas of gabbro. The rock is deep grey, passing towards black, and the surfaces of augite and rhombic pyroxene give it patches of almost metallic lustre.

The olivine-gabbros find their grandest British development in the heart of Skye. The rock is there typically dark, blue-black to brown-black, with similar structure to that of Carlingford. Its joints allow of deep vertical clefts being cut in it; but it does not flake away evenly like granite. Its felspars, being devoid of alkalies, do not break down like orthoclase and albite; and their products of decomposition, which are usually hydrous silicates of lime and iron, tend rather to consolidate and strengthen them. The uniformity of decay noticeable in granite does not occur, therefore, in olivine-gabbro, although the olivine itself alters into dusky serpentine. Moreover, the varied and frequent joint-surfaces give rise to a number of fantastic peaks. At the mouth of Glen Sligachan we have the fine contrast of the pale dome of Glamaig and the uniform cone of Marsco, the granite mountains, on the left; while on the right, above the fern and bogland, rise the black crags of Sgùrr nan Gillean, where some of the huge saw-teeth of the gabbro actually overhang their base. As we ascend the four miles of the glen and cross the low watershed on the *col*, we approach what is absolutely the sternest and grandest scenery of the British Isles. The enormous wall of Blaven now rises vertically from a desolate hollow, its crest, 3040 feet above the

sea, cut by steep gullies in which snow may lie throughout the summer. Scarcely a ledge of grass can rest upon it, and the powdery taluses at its foot are themselves singularly steep. The blackness of the rock adds to its impressive wildness; the granite masses are now left behind, and, as we climb a shoulder on the west, we look down on the hollow of Loch Coruisk. This narrow lake, almost at the sea-level, is nearly two miles long, and is surrounded by mountains rising some 3000 feet above it. Grass spreads freely over the lower slopes, but is seldom touched on by the sun. The general impression is one of loneliness and gloom, and the huge cliffs catch now and again long drifts of the Atlantic cloud. The great combe at the lake-head, the "hollow of the waters," is bound by black crags which rival Blaven; but here they are massed together, leaving between them only the cañon of a foaming stream. Beyond the grim wall on the west, another rises, still more pinnacled and precipitous; and for a long time these ridges of the black Cuchullins were regarded as absolutely inaccessible.

On the seaward side the valley opens into a broad fjord, Loch Scavaig, its barren gabbro walls repeating the features of Loch Coruisk. The horizontal scale of these landscapes is readily forgotten, and black crags fully four miles away seem to tower above us in this grim dark fastness of the rocks. It is a scene to be alone in for a time; and then all the legends of the storm-gods may be realised, as the faint gleams of sunlight sweep across the lower slopes, and the cloud-wisps come and go above the desolate hollow of the lake.

As we return to Sligachan, all the granite hills flush rose-red in the glow of evening, until they resemble the Pyramids in an Egyptian sunset; but even now the Cuchullins remain dark and cold. To-morrow we can wander across their less frequented passes, where there is still a chance of startling an eagle in some hollow filled with the sea-mist. And we shall find that this igneous core, this cleft heart of a volcano, is at least as complex in its details as our open granite highland.

The Cuchullins are, indeed, seamed with dykes and veins of basalt and of fine-grained gabbro. Igneous activity clearly went on long after the intrusion of the main mass that now forms the mountains. The latter mass itself sends off sheets

into the surrounding basalts, and has in places a remarkable flow-structure and banding, which were set up when it was in a viscid state.[1]

It is not surprising that the constituents of a coarsely crystalline rock should be dragged out and arranged in a particular direction, as the mass gives its last movements prior to its consolidation. The edges of many granites show a streaky grouping of the constituents, particularly of the micas, the flow-structure being parallel to the plane of junction of the granite and the surrounding rock. But it is more difficult to account for the occurrence of distinct bands of rock of different compositions, such as we may come across on the surfaces of exposed slabs in the field.

In many cases the appearance of banded structure is due to one igneous rock having been penetrated by another. Such an invasion often remelts the older rock, and a mingling of the two occurs along the surfaces of junction; but the second rock proceeds to work its way forward in a series of parallel sheets, aided by some previous structure in the mass into which it has intruded. Thus, south of Newcastle in County Down, a rock which may be described as a somewhat crystalline rhyolite has penetrated a massive dyke of fine-grained gabbro, and a banded structure has been set up parallel to the flow-planes of the original dyke. The gabbro has opened along these planes, and the invader has taken advantage of them.

But in Skye it is thought that a separation of the molten rock into materials of differing composition had already taken place in the great caldron down below, and that an igneous mass already possessing a certain structure was thus intruded into the position where we now find it. In this upward movement, the lumps, so to speak, of one variety of the rock pressed against those of other varieties, and the whole became squeezed out into parallel sheets.[2] The chemical composition, and therefore the proportions of the resulting minerals, differ considerably in neighbouring bands; one is thus found to be rich in labradorite, and has a silica percentage of 52.8, while another consists largely of augite, with a silica percentage of only 29.5.

[1] Sir A. Geikie and J. J. H. Teall, "On the Banded Structure of some Tertiary Gabbros in the Isle of Skye," *Quart. Journ. Geol. Soc.*, vol. l (1894), p. 645.

[2] Work quoted above, p. 653.

This brings us to the interesting consideration of the origin of the varieties of igneous rocks. As yet we are only on the threshold of this important subject, and we can do little more than state the problem. Are all igneous rocks, as known to us in the upper layers of the earth's crust, the products of chemical and physical separations from a uniform molten mass below? Or are there distinct types of lava ready prepared in separate rock caldrons, which sometimes open at distinct points on the surface, or sometimes, at successive periods, at the same point?

The same volcano may erupt rhyolites for many years, and then proceed to emit nothing but basalts. Has the caldron beneath it become filled by a new material from some other source, or are we now receiving the results of a separation which went on long ago in the melted mass beneath our feet?

In special localities we can actually observe, on the rocky surface formed by the exposed and denuded caldron, how a separation took place in the mass before it finally crystallised and cooled. We have already said that a granitic mass may be a true granite, with orthoclase, at one end, and a quartz-diorite, with plagioclase, at the other. Professor Vogt[1] has studied an extreme case at Huk, near Christiania, Norway, where a dyke, ten metres wide, consists of a porphyritic mica-syenite in the centre and a fine-grained mica-diorite, rich in magnetite, at the margins, the silica varying as we go outwards from 63 to 47 per cent., and the iron oxides from 3 to 12.5 per cent. At Ekersund in Norway, Vogt finds igneous rocks, well-developed diorites, consisting of labradorite, rhombic pyroxene, and titanic iron ore (an oxide of iron and titanium), in which the ore in places forms 80 per cent. of the rock; and he believes these masses to have separated out from a uniform molten rock, the other extreme product of which is seen in the same district as a granite containing rhombic pyroxene.

Messrs. Dakyns and Teall,[2] in a paper of great interest, dealing with intrusive masses near the head of Loch Lomond, have suggested that rocks composed only of magnetite and

[1] See review by J. J. H. T[eall], *Geol. Mag.*, 1892, p. 84; and Teall, "The Sequence of Plutonic Rocks," *Natural Science*, vol. i, p. 288.

[2] "The Plutonic Rocks of Garabal Hill and Meall Breac," *Quart. Journ. Geol. Soc.*, vol. xlviii, p. 118.

olivine, or of pure magnetite, may arise in igneous caldrons by extreme processes of separation. The area discussed by these authors contains rocks varying from a type consisting of olivine and augite only, with a silica percentage of 38.6, to a fine-grained granite with silica equal to 75.8 and potash to 6.5 per cent. The authors believe that the whole complex series has resulted from one original lava-basin.

On the other hand, we are now ascertaining how the intrusion of an igneous rock into an older one often remelts the latter and allows of the most intricate and delicate intermingling of the materials of the two. At times only certain of the constituents of the invaded rock become melted; and then the invader, in a liquid state, penetrates in between the remaining crystals, uniting with the remelted matter and finally crystallising as a new groundwork to the rock. Here we have a composite rock-mass produced, of a very puzzling character. Without careful study in the field, and a series of microscopic sections, we could not possibly work out its mode of origin. Occasionally the results are extremely deceptive, and give us serious warnings as to concluding rashly on the origin of porphyritic crystals. In one case[1] a fine-grained but porphyritic granite has intruded into a large dyke of andesite. The glassy groundwork and the pyroxenes of the latter have partly melted, and the molten highly silicated rock has penetrated in among the small unmelted plagioclases. But the porphyritic crystals of quartz and orthoclase, which were already floating in the invading mass, have been carried into the yielding sponge-like substance of the partly melted andesite. When all has cooled again together, the general effect of the new mixed rock is still that of a dark andesite; but it has become stuck full of conspicuous crystals of quartz and flesh-red orthoclase.

The conclusion is that similar processes of admixture and interpenetration may go on on a large scale underground. Professor Sollas[2] has argued that any separation of the material available for the manufacture of igneous rocks has already taken place during the consolidation of the earth's crust; the remelting of one of these layers by local causes

[1] G. A. J. Cole, "On Derived Crystals in the Basaltic Andesite of Glasdrumman Port," *Trans. Roy. Dublin Soc.*, vol. v, p. 239.

[2] "On the Volcanic District of Carlingford and Slieve Gullion, Part I.," *Trans. Roy. Irish Acad.*, vol. xxx (1894), p. 509.

would give us a well-marked type of rock in any lava-basin that might be established. The inflowing of material from another layer before the first was exhausted might produce a mixed rock of intermediate composition; or, if the new material entered after the first had been extruded in the form of lava, the character of the eruptions on the surface above the caldron might become abruptly changed.

But we must not now attempt to follow out these somewhat speculative trains of thought. We have at any rate seen the interest of any observations that we may make on the contact of one igneous rock with another, or on the occurrence of different bands in the same dyke or intrusive mass. Day after day we may revisit our granite or our gabbro highland, and note the variety of its mineral characters from one end to the other. Dykes and seeming offshoots must be traced, if possible, to their parent mass. Lumps of other rocks that have been picked up by the invader must be studied, with a view to seeing if any have been partly or wholly absorbed; for such an absorption would naturally cause a local variation in the characters of the intrusive mass. And all day long in our researches our feet are wandering on the bare rock or the heather, or on the crisp short mountain-grass; the clouds drive up the great valleys beneath us and creep across the wind-swept *cols;* and the crumbling tors upon the ridges seem dead and coldly crystalline, and are damp even at noonday with the penetrating mountain-dew. Yet before us rises, like a grim and fantastic vision, the picture of the seething and struggling of this ancient caldron, buried four or five miles underground; and in the bared slabs of granite, seamed with dykes and veins, the earth has yielded up another of its secrets to us.

CHAPTER VIII

THE ANNALS OF THE EARTH

We have hinted that the age of igneous rocks can in some measure be discovered by examining their relations to the surrounding strata. If they intrude into the latter, their date must be later than that of the deposition of the stratified rocks. If, however, the igneous masses are overlain by beds which contain pebbles worn from them, they must be distinctly older than those beds. If, again, tuffs and lavas lie among strata in regular layers, being thus, as we say, "interbedded" with them, the igneous series and the strata are of the same geological age.

But how shall we discover to what period of the history of the earth these stratified rocks belong? How shall we divide up the long past ages of which we have no written records?

It is clear that in any limited district we may be able to work out the order of succession of the deposits. Where one group of strata is lying upon another, and where the rocks do not appear to have suffered from any great disturbance of the earth's crust (see Chapter X), it is obvious that the upper beds will be newer than the lower. When they lie, like courses of masonry in a fair building, evenly upon one another, we say that they are *conformable*, and that they have been deposited steadily in the same great hollow of the crust; probably this area was slowly sinking, and thus allowed room for each fresh stratum spread upon it. Where, however, one set of rocks has been uptilted and denuded, a second set being deposited across its worn-down edges, we say that we have an *unconformable junction*, or an **unconformity** (fig. 20). Every modern beach is thus unconformable to the shore on which it is being laid down. In our walk along the shore (p. 95), we saw a junction of this kind, where sand and boulders were accumulating across the ribs produced by the upturned edges of old strata.

An unconformity may thus be visible at a glance in a quarry or in a cliff-section; but in many cases it may be necessary to trace out the junction for some miles, the degree of tilting of the lower series of beds being but slight. However, the irregular and worn surface of that series will often be a guide; and a still surer piece of evidence will be furnished by the discovery of pebble-beds in the upper series, formed of materials derived from the lower series. It is obviously not necessary, in that case, that the contact between the two rocks should actually be visible at any point. If one rock contains pebbles worn from another, unconformity, whether local or far-reaching, is proved satisfactorily, though the true plane of junction may never be discovered.

Unconformity commonly originates in the raising of strata until they come under the influence of ordinary agents of denudation. They thus form a local land-surface, while deposition goes on elsewhere. At some later time, submergence takes place, and strata are laid down in the excavated hollows of the hills, and finally even across their ridges. There has been, however, a marked interval between the two series, of which no record, beyond, perhaps, a few terrestrial deposits, has been preserved. To fill up this gap, we must go elsewhere, to some region where elevation did not take place at the same time. Hence, could we know the whole world, we could compile a complete history from its stratified deposits, every local unconformity being represented by a conformity somewhere else.

Occasionally, as the *Challenger* observers have found, even in water 1700 fathoms deep,[1] the soft but partly consolidated sea-floor may be disturbed by currents and may become broken up, irregular lumps of the beds that were formed under conditions more favourable to deposition becoming rolled along and banked together, finally to be covered by a new stratum. This is a special case of unconformity, the cause of which has been a change in the direction of currents, and not an upheaval of the sea-floor. In this way, in the "Carboniferous limestone" of County Dublin, lumps of a similar rock occur, evidently derived from the underlying beds of the same series; remains of corals, sea-

[1] See W. F. Hume, "The Genesis of the Chalk," *Proc. Geol. Assoc.*, vol. xiii, p. 231.

lilies, &c., may be found within the lumps, and other examples of the same species may have used these rolled blocks as a basis for their growth. In such a case the unconformity must be fairly local in character. The whole series of strata is, indeed, conformable, when judged by the regularity of its bedding; and no long interval is represented by the phenomena of the blocks derived from earlier layers.

Sometimes two or more unconformities may occur in a small space of country. Thus on the shore at Skerries, in the north of County Dublin, the sea has exposed a series of altered shales, which we will call A; a limestone series, B; a gravel series, C; and it is also here and there depositing the present beach, D. The tilting of the beds A and B does not correspond, so that we suspect an unconformity, although the water covers the actual junction. The case is proved, however, by the occurrence of a magnificent old beach in the series B, formed of great flaky pebbles worn from A. A little farther south, certain beds of B have been churned up, as described on p. 217, giving us a second unconformity, but a purely local and trivial one. In the little cliff above, on the other hand, a very obvious unconformity is seen between B and the gravels C, the latter lying across the edges of the beds B, while the surface between has been ground down and striated by glacial action. C contains scratched blocks derived from both B and A, together with a number of materials borne by ice and rivers from distant areas. Finally, the modern beach D is being formed from the decay of all the preceding deposits, and in places resembles, repeating the details with the most interesting accuracy, the very ancient beach exposed in contact with it on the surface of the series B. Thus in three hundred yards or so we have three principal unconformities, and one trifling one, the latter being due to local changes in the conditions under which the strata B were being deposited.

In an unconformable junction, the lowest bed of the upper series crosses, as we have said, the worn-down edges of the lower series; and this bed is said to successively *overstep*[1] those beneath it, one after another (fig. 20). Again, in the basin-like hollow of a sea or lake, particularly if its floor is sinking, each successive stratum of the upper series

[1] This term is due to Mr. J. G. Goodchild; see also Jukes-Browne, "Physical Geology," 2nd edition, p. 548.

extends farther across the lower and unconformable series than does the stratum which lies immediately below it and in conformity with it. Thus the first stratum of the upper series occupies only a small area on the floor of the hollow; the next, resting conformably on it, spreads more widely; and this increase in the area of successive layers becomes the more marked, if the shore against which they are deposited is a gently shelving one. If the coast drops downward, on the other hand, in a vertical wall, as in some Norwegian fjords, this difference between the layers is of course abolished. The spreading of any one layer of a conformable series beyond the limits of the underlying layer or layers of the same series is spoken of as *overlap* (fig. 17).

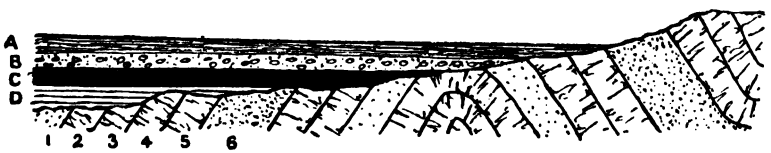


FIG. 20.—UNCONFORMABLE JUNCTION, WITH OVERLAP AND OVERSTEP.

The series A–D is unconformable to the series 1–6, &c. D oversteps successively 1, 2, 3, &c. C overlaps D, and is overlapped by B, which is in turn overlapped by the youngest bed, A.

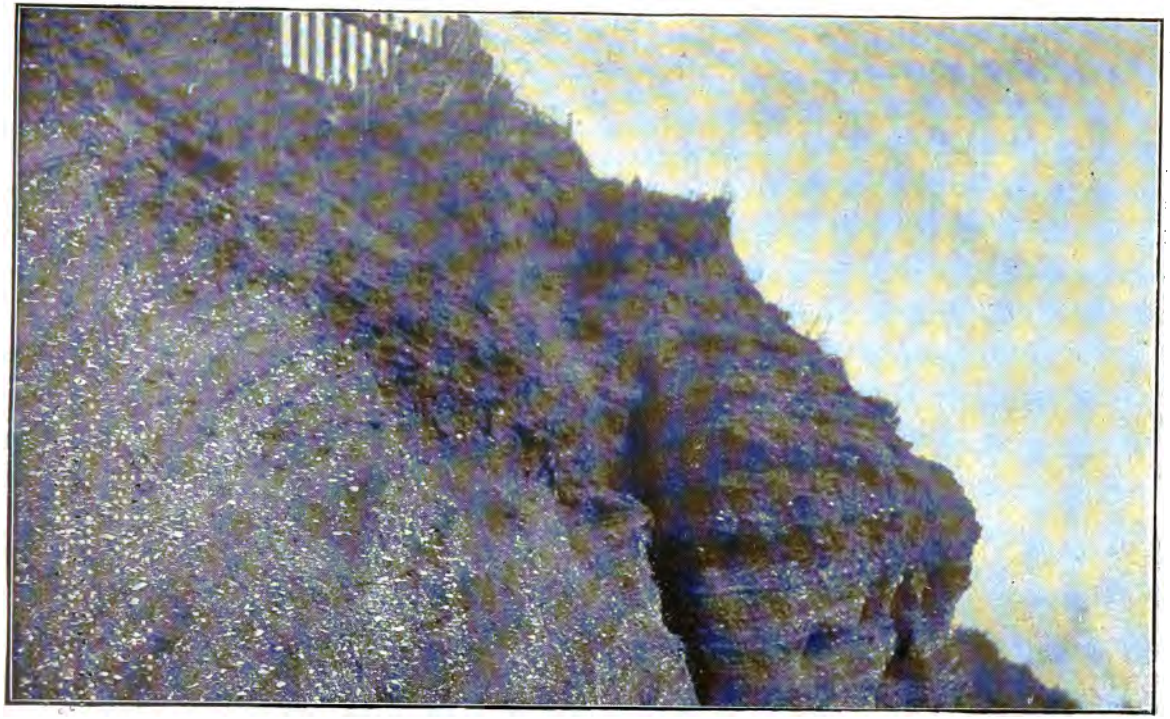
Thus in any one district the relative ages of rocks, whether sedimentary or igneous, can be fairly made out, and we can even learn a good deal as to events which took place between the formation of one series and another. But what we want is to be able to go up to a rock-mass in any region, and to discover from its special characters the period at which it was constructed. It is improbable that we shall ever be able to do this in the case of igneous rocks, seeing that lavas and intrusive masses do not seem to have changed their nature from the time of the earliest eruptions until now; and all attempts to classify such rocks according to their geological age have hopelessly broken down. Similarly, sandstones and clays and limestones seem to have existed in all times, and a limestone may be deposited in one part of a sea while a sandstone is being deposited simul-

taneously in another. Even the crystalline rocks called schists and gneisses (Chap. X) may belong to very different ages.

Thus we say that, in the case of any rock, "lithological characters," *i.e.*, the nature and structure of the stone itself, are useless in assigning it to its place in the annals of the earth. We have now, however, another and a remarkable guide, which we can employ in any quarter of the globe.

We are all acquainted with **fossils** (Plate X). By this term we now mean the remains of any plant or animal that are found included in a rock.[1] We must use our discretion as to how far we should apply the word "fossil" to modern cases of entombment. A goat might become involved in a recent mud-flow on the flanks of a mountain; the rootlets of living plants, again, penetrate a long way down into the crevices of rocks; but neither of these cases gives rise to fossils in the generally accepted sense. Some fossil shells have preserved even their lustre, while the calcium carbonate of others has actually become changed, molecule by molecule, into some other chemical substance. Silica, iron carbonate, iron sulphide, and gypsum, are thus found actually replacing the original shells or hard parts of many organisms; and silicified tree-stems are well known from many parts of the world. Very often, all that is left us is a cast, formed by the fine particles of the rock itself, which have penetrated the hollows of the shell or skeleton and have taken an accurate mould of them. Clay forms excellent *internal casts*, and the fine limestone-mud associated with shell-banks has a similar effect. Often the substance of the fossil itself has become dissolved away, after its entombment, and a hollow space has arisen; but the enveloping and consolidated rock has at the same time taken an *external cast* of the fossil, from which many of its characters can be ascertained. Moreover, an internal cast may have been formed as well, which is generally fixed to the surrounding rock at the points where the material penetrated into the hollow of the shell. In some cases, however, the solution of the shell leaves the internal cast to rattle loosely

[1] Up to the earlier years of the present century, a "fossil" meant anything dug up (*fodio, fossum*) out of the earth, and the objects to which the term is now restricted were called "organised fossils."



FOSSIL SHELLS IN PLIOCENE SANDS, FELIXSTOWE, SUFFOLK.

PLATE X] [*Photographed by* Mr. FRANK WOOLNOUGH.

inside the external one, and to fall away when we break open the block of stone.

Excellent internal casts can be seen in the rougher beds of Portland limestone, known as the "Roach bed." The objects called the "Portland screw" are the internal casts (fig. 21) of a long spiral gastropod shell, a *Cerithium;* and casts of a bivalve mollusc, *Trigonia*, are also frequent. In the latter, the depressions where the muscles were attached to the shell are of course represented by raised oval patches, and the teeth of the hinge, which are beautifully ribbed with fine ridges, are recorded in reversed pattern on the cast.

Casts are most common in sandstones, owing to the permeability of the material, and are frequently the only indications of fossils throughout the rock. In clays, on the other hand, even the most delicate fossils, such as foraminifera decorated with fine spines, are generally well preserved.

FIG. 21. — INTERNAL CAST OF A CERITHIUM, PORTLAND STONE.

Internal casts are often formed of marcasite, so that we have a mould of the fossil apparently modelled out of shining brass. These handsome specimens are unsatisfactory for collections, since so many, in the course of years, go to pieces through decomposition of the iron sulphide (see p. 17).

Fossils, we should also note, often serve as a centre round which chemical substances present in the rock collect. **Concretions** are thus formed, which are commonly harder than the rock itself, and which are seen sticking out on quarry-sections, or on cliffs, along the lines of bedding. At Whitby, for instance, where every visitor learns to be interested in geology, the concretions of calcium carbonate in the shales are pretty certain to reward the fossil-hunter. They can be broken open by the hammer along the bedding-planes that pass through them, and most frequently a perfect specimen of an ammonite is found lying, brown and lustrous, in the middle.

While dealing with fossils, we may perhaps note how even the tracks and footprints of animals (p. 104) may be preserved by the gentle deposition of a stratum above that

in which the impressions were made. Similarly ripple-marks, water-groovings, sun-cracks, and rain-prints are often exquisitely "fossilised." Usually the footprints can be best studied on the under-surface of the covering bed, on which they stand out as casts. Worm-burrows, again, may be filled up by fresh sand, perhaps of a different colour to that in which the animals bored; and such traces of worms are sometimes the only evidence left to show us that life existed in the area in which the beds were being laid down.

Fossils must long ago have been observed by the primitive peoples of the earth, and may have been regarded, like meteorites, with a certain amount of reverence. Mr. Worthington Smith[1] records a case where the body of a girl, in a tumulus of the bronze-age near Dunstable, was found surrounded by 158 sea-urchins collected from the Chalk, more than half of which were perfect specimens. It is probable, then, that some mystery was held to attach to these strangely shaped objects in the earth.

The ancient Greeks recognised that fossils were the remains of creatures which once lived in the places where they now are found. They saw that, from one cause or another, land and sea had changed places, and that marine shells had often been left high and dry.[2] It seemed, however, difficult to conceive that a sufficient number of changes had gone on to account for the great variety of beds of rock crammed full with animal remains. Aristotle, in the fourth century B.C., thought to help on matters by suggesting that the earth itself contained a mysterious force within it, whereby animals grew in moist rocks, which subsequently consolidated and enclosed them. Such animals, we may presume, were like the toads that are sometimes found in hollow stones, living and breathing, but never seeing the world around them. We now know, however, that such toads have entered the hollows of the rocks in an infant form, and subsequently have grown to larger size. This idea of the development of animals in the earth itself spread very widely, and formed one of the chief errors that early

[1] *Nature*, vol. xliii (1891), p. 320.

[2] See Sir C. Lyell, "Principles of Geology," opening chapters; and O. C. Marsh, "History and Methods of Palæontological Discovery," *Nature*, vol. xx, pp. 494 and 515.

geologists had to fight against. Even in the eighteenth century, opinion was greatly divided on this point; and the teachings of Professor Beringer of Würzburg seem to have been in favour of the plastic force as recently as 1726. The solid globe was supposed to be like an Italian image-maker, continually turning out pattern after pattern and copy after copy, some of them like things in heaven or earth, and some of them entirely works of fiction.

Professor Beringer went so far as to publish a book entitled "Lithographiæ Wirceburgensis, ducentis lapidum figuratorum, a potiori insectiformium, prodigiosis imaginibus exornatæ specimen primum," in which he represented, on twenty-one small folio plates, some of the most extraordinary fossils ever discovered in his or in any other district. This work, which was guided and inspired by Beringer, appeared under the name of Hueber, a student of the University, for whom it served as a thesis for his Doctor's degree.[1] The drawings include a variety of insects with extended wings, spiders with their webs, crustaceans and slugs, and a few respectable-looking shells. Vertebrates are represented by frogs, fishes, and (plate iv) the most grotesque birds, two of which have eggs lying beside them. Flowering plants are also figured; but the greatest marvels are certain stones bearing carvings of the sun and moon, comets and stars, and finally even Hebrew letters (plate vii) in relief. These letters, including the name of Jehovah, were found occasionally on the surface of marine shells. One would have thought that such wonders would have raised suspicion in the minds of their discoverers; but young Dr. Hueber defended them as being the work of Nature, and as being intended for the spiritual edification of his compatriots.[2]

Unfortunately, the whole series of specimens proved to be manufactured by a humorous ex-Jesuit named Rodrick (? Roderick), who was tutor to the children of one of Beringer's colleagues. This ingenious if unscrupulous man hired small boys to bring the "fossils" to the professor, asserting that they had found them in a neighbouring hill. When Beringer very properly wished to investigate matters

[1] See Ph. X. Leschevin, "Notice sur *Lithographia Wirceburgensis*, et sur la mystification qui y a donné lieu," *Magasin Encyclopédique*, tome vi (1808), p. 116.

[2] "Lithographiæ Wirceburgensis, &c.," p. 70.

on the spot, similar "figured stones" were buried ready for him to find. When Hueber's work appeared, the explanation of the fraud, and the apologies of its author, came too late to save Beringer from ridicule. He bought back as many copies of the book as he could procure; but these and the remaining stock were somewhat cynically reissued, with the suppression of Hueber's preface and under Beringer's own name, after the death of the unfortunate but credulous professor.

It is probable, however, that we all, like Beringer's acquaintances and pupils, have pulled out sufficiently remarkable fossils for ourselves from the solid rocks. If we go, for instance, to the vales of Derbyshire, we find whole blocks of limestone composed of shells. These stand out on the weathered surfaces; and we also see numerous cylindrical bodies, with a hole down the centre, which are pieces of the stems of sea-lilies; and curving fragments of bivalve shells, which belong to a class known as the Brachiopoda; and spirally coiled univalves, representing an early type of Gastropod. In a holiday in Dorsetshire, again, we may find looser yellow limestones and white chalk, in which the shells are still more beautifully preserved; and in the Isle of Wight, particularly at Totlands Bay, there are clays and sands from which we can detach the fossils with our fingers. We may make collections at all these places, and may keep them in separate drawers when we go home. If we compare them carefully, we shall notice that the kinds of fossils from any one of these localities are not the same as those from either of the others; after a little time, we might be able to mix them up, and then sort out those from the grey limestone of Derbyshire, the softer limestones of Dorsetshire, and the sands of Totlands Bay, by recollection of their special characters.

But, if we go to the fine quarries above Cheltenham, we shall find many of the same fossils as occur in the yellow rocks of Dorset; if we go to the flanks of the Mendip Hills, we shall find others agreeing with the shells of Derbyshire; and hence we see that the same kinds of fossils occur in widely different districts.

For purposes of recognition, geologists, like zoologists and botanists, have to give each distinct kind of plant or animal a name; and these names have to be of such a character that people in any civilised nation can make use of

them. By common consent, the classical languages, Greek and Latin, have been used as the foundation for such names; and, until recently, Latin was the language commonly used when any book was intended to be read in more than one European country. Plants and animals are grouped, as we know, into great "classes," and then into "orders"; and then these are divided into "families." Each family contains one "genus," or a number of "genera," and each genus consists of one or more "species." When we wish to refer to a particular species, which has been described by some observer as distinct in one or more of its characters from all other species, we use the name of its genus, followed by that assigned by its discoverer to the species. For instance, there

FIG. 22*a*.—*Pecten Beaveri* (Cenomanian stage, Cretaceous period).

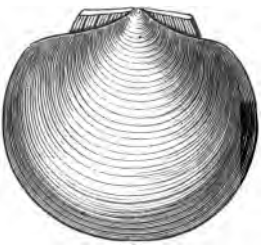


FIG. 22*b*.—*Pecten cinctus* (Urgonian stage, Cretaceous period).

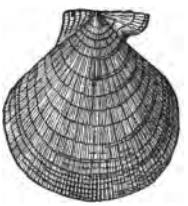


FIG. 22*c*.—*Pecten islandicus* (Recent period).

is at present living a series of bivalve molluscs which are placed in the genus *Pecten*, a name referring to the comb-like markings or ribbings on their surface. Among these, sufficient differences have been observed to necessitate their grouping into more than a hundred species, such as *Pecten maximus* (the Scallop), *Pecten nobilis*, *Pecten opercularis*, &c. (Compare figs. 22*a*, 22*b*, and 22*c*.) In each case, the second name is, as we say, "specific."

Hence we have to go with our fossils to the zoologist or the botanist, before we can give them proper names. But again and again we find that no living species is quite like our ancient specimen, and we learn that very many species have disappeared from the surface of the earth, or

have become *extinct*. Thus there are about four times as many extinct species of *Pecten* as there are living ones. Moreover, a great number of our fossils cannot be fitted into any existing genus, and even many families and orders are only known from fossil specimens. Could we continue to push our observations over the rocks of the whole of our islands, we should soon become convinced of the extensive changes that have taken place in the prevalent kinds of animals and plants since the dawn of life upon the globe. The assemblage of animals living in any district at the same time is called its *fauna*, the assemblage of plants being called its *flora*. We should find in time that whole faunas and floras of past ages had become entirely extinct.

The fossil fauna of the Derbyshire limestone occurs, as we have seen, in parts of the Mendip Hills; that of part of the Dorset coast is repeated in the Cotteswolds. It was reserved for a hard-working and observant land-surveyor to piece together such facts as these, and to read from them for the first time the annals of life upon the globe.

William Smith was born in western Oxfordshire in 1769,[1] high up on the plateau of the Cotteswold Hills, and must have been familiar from his childhood with a rich variety of fossils, which roll out into the roadways from the limestone cuttings, and which are even used for making the roads themselves. Brachiopods and lamellibranchs and cephalopods, well preserved starfish and sea-urchins, must have convinced him very early of the former extensions of the sea; and we may picture him wandering down the steep lanes to some particular quarry for one kind of fossil, and across the windy fields upon the ridges for some other of which he knew the exact locality.

We know, at any rate, that at about the age of twenty-one Smith had discovered that fossil faunas succeeded one another in regular order. Certain assemblages of fossil species were always, as he showed, to be found underlying other distinct assemblages; in other words, *strata could be identified by the fossil faunas that they contained.*

Thus, in section after section, he observed that one set of fossils, which we will call A, was followed, as he went upwards in the series of strata, by a set that we will call B, and this by a set C, and this by a set D. The order was con-

[1] John Phillips, "Memoirs of William Smith, LL.D.," 1844.

stant. Even if, from some local cause, B was missing, C would be found resting upon A. After gathering a large amount of evidence, William Smith found that the occurrence of fauna C, for instance, would enable him to predict that fauna B or fauna A lay somewhere down below. Hence the past history of life upon the globe was marked by a succession of faunas, and the observation of any one of these by itself would enable us to say that the rocks containing it were made at such and such a period of that history.

In this way the annals of the earth were laboriously compiled. William Smith extended his experiences, while working as a civil engineer on the Somerset Coal Canal; whether lodging in some country-inn, as at Dunkerton, or in his own house at Midford, he became thoroughly acquainted with the fossiliferous strata around Bath. In those days, the modes of travelling encouraged observation of the country. Hills and valleys were important features to the post-chaise or the coach, just as they are to the modern cyclist. The traveller could look far ahead, without, as now, the risk of receiving coal-dust in his eye or of having his head taken off by a bridge-pier; and the colour of the cuttings or of the distant quarries could be traced from ridge to ridge across the landscape. In leisurely driving, hills might be walked, and rocks might be examined along the roadside; and quaint local specimens could sometimes be picked up on the chimney-pieces of wayside-inns. In traverse after traverse of England, Smith assured himself of the truth of his doctrine of regular succession; and he gave names, as Professor Werner had done in Saxony, to the several sets of strata that he came across. In 1800 he made a memorable journey, on behalf of Mr. Coke, to Holkham in Norfolk, where he busied himself in resisting the inroads of the sea by constructing protective banks. We can picture his keenness as he ascended the great plateau of the Cotteswolds above Bath, crossing his "Under Oolyte" and "Great Oolyte" limestones, and as he traced out his well-marked divisions into the district of the "Oak Tree Clay" near Oxford. The long ridge of "Green Sand" and "Chalk," capped by its dry plains,[1] lay upon his right; and finally these also had to be surmounted as Cambridge was approached. Still moving north-eastward, he

[1] William Smith, "Memoir to the Map and Delineation of the Strata of England and Wales" (1815), p. 42.

came across the barren heaths of Suffolk and Norfolk, where the decay of the Chalk strata has covered the country with angular flints and sand, giving rise to what Smith calls "the greatest breadths of poverty and wretchedness." Doubtless his wheels sank into the loose and almost abandoned roads, which are hardly likely to have been better than the tracks of west Suffolk in our own time. And finally he came over the rim of the Chalk again, and saw the modern sandy reaches stretching at the foot of Holkham woods, and the cold line of the North Sea breaking on them, and arranging new strata on the shore. A journey of this kind was to him full of a sober joy, and he went forward map in hand, with the scheme for a "delineation" of our strata already in his active mind.

Naturally, he made some mistakes as to the order of superposition of certain beds. Where a set of strata appeared to him resting on another set below, he might easily have overlooked some unconformity that had occurred, and have placed the two in direct succession. The beds that properly filled the gap might be discovered elsewhere, and might come to be placed in his classification above those with which he had first become acquainted. But in time he produced a convincing work, illustrated by Sowerby, entitled "Strata Identified by Organized Fossils," of which four parts alone were issued. These are now rarely met with, but they effected their purpose in a very few years. About the same time (1815), Smith received Government assistance towards the construction of his great map of England and Wales, on which his principles of the classification of strata were displayed. The areas occupied by the various divisions of the strata were coloured with washes bearing some resemblance to the colours of the actual beds—a plan that has ever since been adopted by the surveys of the British Isles.

Thus the great discovery, first circulated by Smith in manuscript in 1799, became open for the approval and criticism of all. The foundation of what we now call *stratigraphical geology* was firmly laid by this busy professional man, who, but for his open-air studies, might easily have remained merely a successful civil engineer.

Smith chose the names of his series of strata mostly on account of their local peculiarities, or from terms used by quarrymen and farmers. Sometimes a district gave its name

to a series, and this plan has since been widely followed. No uniformity is discoverable, however, in the names employed by any geological survey; and many of our British terms have become translated and adopted by every foreign country. Of late years, an agreement with regard to some points has been arrived at, for mutual convenience, by means of the International Geological Congress; and the following terms have been put forward for divisions of stratified rocks and for the periods of time occupied in their formation.

The largest divisions of strata are styled, on this conventional plan, *Groups*. These are divided into *Systems*, and each system is divided into *Series*. These again are formed of *Stages*. The time-divisions corresponding to these are as follows :—

Stratigraphical Divisions.	Time-Divisions.
GROUP.	ERA.
SYSTEM.	PERIOD.
Series.	*Epoch.*
Stage.	Age.

It must not be supposed, however, that each stage, or series, or system, or group, took the same time to accumulate as any other stage, series, &c. The extent to which, from our studies in the field, we agree to subdivide any particular division of the stratified rocks depends greatly upon our detailed knowledge of it; and thus the stages of the later groups, the beds of which are so much the most convenient to study, represent briefer "ages" than many of the older ones. A whole system, moreover, may sometimes be established in a country where two unconformities, one above and one below, cut it off sharply from the other systems; but subsequent research may show that in some other country this system is so closely and continuously connected with the one above or the one below that it would not have been worth while to distinguish it by a separate name, had observation commenced in that particular area.

The one principle of classification on which we now rely is that fossil faunas are to be our guide, and not the lithological character (p. 220) of the beds in which they lie. The fauna of one district may have spread only slowly to another, so that strata containing the same fauna were not necessarily deposited at exactly the same time; but this will not affect

us in assigning "ages" to the beds of any particular area. Species, moreover, varied, as they do now, from point to point, and we must thus, in our classification, regard the general aspect of a fauna rather than its minutest details. Some genera, and even species, have managed to persist through such a long succession of periods that they are of no value in classifying strata; others arose and vanished away in so short a time that they mark out "ages" very precisely. Where a fossil species occurs abundantly along a particular bed or set of beds, being restricted to it, or being only poorly represented above and below, we say that it marks a zone. We can thus speak of "the zone of *Actinocamax plenus*" (see Chapter IX), or "the zone of *Pentamerus oblongus*."

By common consent, marine types of life have been used as the most convenient means of classifying strata. Fossils are rare in fresh-water deposits, and terrestrial deposits are very seldom preserved. A good deal of our knowledge of the land-animals of the past is, indeed, derived from the fact that their remains have been washed down into the strata which were forming on the shore. Marine beds, on the other hand, quickly and securely entomb any dead shells and bones that become mingled with them, while the abundance of life in the sea gives us plenty of material by which we can judge the character of the fauna.

In the later chapters of this book, we shall have frequent occasion to speak of the "systems" established by geologists; and their names, thanks to the writers of popular works and guide-books, are beginning to be fairly familiar as household words. Considering what vast eras are covered by the annals of the earth, as written in its fossil faunas, it is important to have some means of referring to particular periods. I am afraid, then, that the following table should be committed to memory; it is not more difficult than the lists of kings which we have to deal with in our studies of human history, and it represents a series of facts of vastly wider meaning, facts which, indeed, form the foundation of the history of every nation in the world.

TABLE OF STRATIFIED ROCKS.

Groups.		Systems.
IV.	CAINOZOIC or TERTIARY.	5. *Post-Pliocene* and *Recent.* 4. *Pliocene.* 3. *Miocene.* 2. *Oligocene.* 1. *Eocene.*
III.	MESOZOIC or SECONDARY.	3. *Cretaceous.* 2. *Jurassic.* 1. *Triassic.*
II.	PALÆOZOIC or PRIMARY.	6. *Permian.* 5. *Carboniferous.* 4. *Devonian.* 3. *Gotlandian.* 2. *Ordovician.* 1. *Cambrian.*
I.	ARCHÆAN.	

I. The ARCHÆAN era[1] is represented by so few fossils that no division into systems can be made. But probably it covers as long a series of periods in the history of life upon the globe as all the other eras put together. Worms and brachiopods are, however, almost the only living things that have left their traces. The oldest rocks of the Archæan group may, of course, represent periods before life actually existed. They consist of completely crystalline masses, like granites, together with others, which we shall learn to call "schists," and which may prove to be highly altered sediments or crushed and drawn-out igneous rocks.

The beautiful ridge of Malvern, which stands up like a blue wave against the sunset, sharply defined above the land of level orchards round it, is now known to be the relic of an Archæan mountain-range. It must have been several times buried in the sea, only to reassert itself as the most striking landmark of our Midlands.

The long desolate islands of the Outer Hebrides are

[1] For local guidance as to the areas in which the several groups and systems are exposed, see the maps and memoirs of the Geological Surveys of Great Britain and Ireland; H. B. Woodward, "Geology of England and Wales;" Hull, "Physical Geology and Geography of Ireland;" Kinahan, "Geology of Ireland;" and Sir A. Geikie, "Scenery and Geology of Scotland."

formed entirely of Archæan rocks, which appear also on the opposite mainland as a floor on which later mountains have been reared. The wild and weather-worn surface of Scandinavia probably offers us the largest European area over which Archæan masses are exposed; and the similar rocks of Scotland, and perhaps patches in north-west Ireland, may be regarded as a continuation from Norway along the edge of the continental plateau.

II. The PALÆOZOIC era is that of "ancient life." Even at the base of the group, there is a great variety of fossil forms, which justifies us in searching diligently among the Archæan rocks for still earlier types of life.

The **Cambrian** period has probably now been most successfully studied in Bohemia and in the north-eastern states of America; but it derives its name from the Roman name for Wales. The black shaly beds on the moors north of Dolgelley, particularly in the boggy hollows north of Rhobell-fawr, contain numerous Cambrian fossils, which are best seen when the surface of a specimen is held obliquely to the light.

The "Silurian" system, named by Murchison after the Silures, who lived in South Wales and the Marches, was divided into a Lower and an Upper series. The former was also called "Upper Cambrian," and some controversy arose over these names. Professor Lapworth proposed in 1879 to call the Lower series "Ordovician," and Professor de Lapparent in 1893 proposed "Gotlandian" for the Upper series. The adoption of both these terms at any rate prevents confusion.

The **Ordovician** period takes its name from the Ordovices, a tribe that formerly inhabited North Wales. Snowdon is formed of tuffs and lavas ejected in Ordovician times; and brachiopod shells occur in the shales upon its very summit.

The **Gotlandian** period is named after the island of Gotland in the Baltic. The whole of its stages are beautifully seen around the town of Ludlow, and fossils are simply abundant in the shales and limestones. A small patch of Gotlandian limestone at the Wren's Nest, near Dudley, has proved the most famous British collecting-ground; but in Bohemia, and the island of Gotland, the fossils are still more richly preserved. The handsome ridge of Wenlock Edge, sloping away eastward on the Bridgenorth side, and dropping

steeply towards Church Stretton and Shrewsbury, is capped by the highest Gotlandian shales; the great scarp, through which the road-cuttings have been made, is formed of Middle Gotlandian limestones; and the long and gentler slope below has the earliest Gotlandians at its base.

The **Devonian** system is mainly represented by fresh-water sandstones in the British Isles, and its marine type is best observed in Belgium. Devon itself, however, contains a complete series of marine strata, the "Plymouth Marble" being notable among them. This delicately tinted rock makes the buildings and walls of Plymouth glorious after a dash of rain, the pink veins of calcite shining then across the grey masses of the limestone. Bent and injured fossils are commonly seen on polished surfaces of this rock, and corals are particularly abundant.

The sandstones formed in the great lakes of the period come up in the centre of the Mendip Hills, but are far more finely seen in the Breconshire Beacons away west. The roadside cuttings in Herefordshire constantly expose these beds, and they cover large areas in Scotland.

The **Carboniferous** system gets its name from the immense amount of coal that occurs amid its higher beds. Plant-life seems to have flourished with extraordinary abundance, and the forest-deposits and drifted snag-banks accumulated to form the most important industrial strata of the world. These deposits are, of course, terrestrial and estuarine, but in many areas the lower series are marine. In Scotland, however, the whole Carboniferous system is estuarine, while in India it is marine throughout.

The lowest Carboniferous series includes great beds of limestone, which are well known in Derbyshire and in the west of Yorkshire, and which are crowded with marine fossils. These strata weather out in huge steps across the landscape, giving a terraced character to the hills. In Ireland, similar features are noticeable in the west, while the central plain is formed also of Carboniferous limestone. Its hollows are occupied by broad lakes, with gently sloping shores; and every here and there the general level is broken by some ridge of Ordovician strata, the weathered-out crest of an island round which the Carboniferous sea once flowed.

In England, great sandy beaches usher in the estuarine and terrestrial series, and the true "Coal-Measures" are at

the top of the system. The Forest of Dean forms an interesting tableland, with the whole system exposed upon its flanks. On all sides we climb up from the sandstones of the Devonian lake, across the Carboniferous Limestone and the central grits, to the capping of shales and coal-seams. The mines are hidden away in a tangle of old woodland, through which the footpaths wander, just as they may have done in the days of Caractacus and Cymbeline. It is a curious high region, still cut off, as it were, from modern Britain.

But the central "coalfields" of England are crowded with grimy villages, while the fume of their chimneys blackens the air over thousands of square miles. At night the sky is ablaze with the flare of iron-furnaces, while red-hot flows of slag run down the heaps like lava-streams. And then suddenly we leave this busy country, with its encroaching spoil-banks and its blackened stems of trees, for a land of green fields and apple-orchards white with blossom, of half-timber farms and churches with square Tudor towers—and we know that we have passed beyond the Coal-Measures to some innocent overlying or underlying series.

In the north of England, the coals are often worked in hollows between folds of unproductive moorland; and the great grits and limestones of the Pennine Chain rise up thus to form a pure mountain-area between the gloomy coalfields of Lancashire and west Yorkshire.

The **Permian** system is insignificantly developed in England, and is only in part marine. In the south it is represented by red beds of conglomerate, containing many angular fragments, such as may easily have accumulated on a land-surface. These strata form the well-known red coast round about the mouth of the river Exe, and extending away to Teignmouth and Torquay. The system was named from Perm in Russia; but in most places it is convenient to regard it as a mere continuation of the Carboniferous.

This sixth system concludes the Palæozoic group. The faunas are throughout markedly different to those of the present day. It is important to note that in the Cambrian beds the highest forms of life known to us, the lords, indeed, of the Cambrian world, are the Trilobites (fig. 23), which were comparatively small marine creatures allied both to the scorpions and to the humbler orders of crustaceans. The earliest known fishes are Gotlandian, and were protected

by a firm bony armour. They found powerful rivals in the successors of the trilobites, "sea-scorpions" some four feet long. In the Carboniferous period, however, the fishes had asserted themselves, and a few amphibian remains have also been discovered. A great variety of shell-fish existed, but the proportions of the several classes were very different to what they are in existing seas. Thus in the Lower Carboniferous Limestone of Ireland we find that, out of 345 species of shell-bearing animals, 37.5 per cent. are brachiopods, 21.9 per cent. lamellibranchs, and 18.1 per cent. gastropods. Out of 527 species recorded from modern British

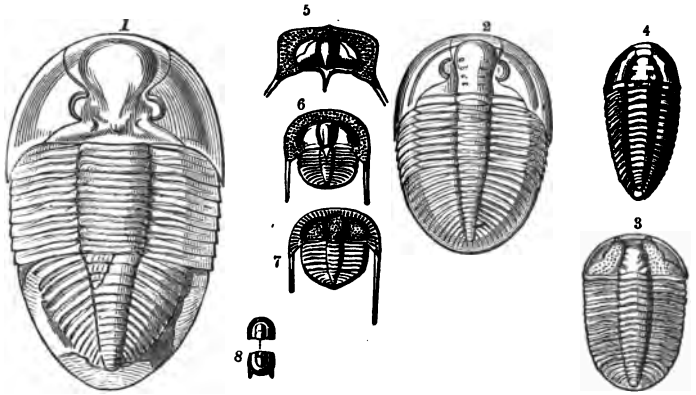


FIG. 23.—TRILOBITES, REPRESENTING AN EXTINCT GROUP OF ANIMALS PECULIARLY ABUNDANT IN EARLY PALÆOZOIC TIMES.

About half natural size. Nos. 5 and 8 are fragmentary.

seas, we have:—Brachiopods 1.3 per cent., lamellibranchs 32.6, and shell-bearing gastropods 48.

Not only the species, but most of the Carboniferous genera are now extinct. If we examine the plants, we find that forms now lowly and insignificant were then as large as forest-trees. They had no rivals in the form of complex flowering plants, and their simple and seemingly wasteful methods of reproduction probably accounted for the rapid spread and growth of forests across every continent.

In Permian times, reptiles began to appear, and became

predominant in the Mesozoic era. Thus even as late as the close of the long Palæozoic era, or probably more than half-way through the history of life upon the globe, it was a struggle between reptiles and amphibians as to which should possess the empire of the world.

III. The MESOZOIC or "middle-life" era opens with the **Triassic** period. This name is derived from the threefold division of the strata in central Europe, where we have a fresh-water or terrestrial series above and below, with a marine invasion in the middle. A second marine series is now, however, included at the summit of the system. The Trias is marine throughout in Tyrol and south-eastern Europe. In our islands it is fresh-water or terrestrial (with the exception of the very highest series), giving us useful beds of salt and gypsum, derived from the evaporation of lakes in a dry climate. The soft current-bedded sandstones, pale pink and red, and the red clays, that cover so much of England from Chester to the base of the Cotteswolds, belong to the Triassic system, and rest on Carboniferous and older rocks in striking unconformity. At the top, as may be seen near Bristol and in County Antrim, we have the return of the sea recorded for us, and marine molluscs occur plentifully in white marls and shales.

The **Jurassic** system is named from its excellent development in the Jura Mountains; but its stages are usually named after English localities, thanks to the start obtained by the stratigraphical geologists of our own islands. We have three series, the lower of which corresponds to the old British "Liassic" system, the middle and upper series representing what was called the "Oolitic" system. The Lower Jurassic series forms the undulating lowland that stretches for 250 miles along the base of the Cotteswold Hills and their prolongations; it is set with clay-pits and occasional limestone quarries, both forming good hunting-grounds for fossils, which are often found replaced by marcasite in the clays. A large part of the face of the Cotteswolds is also formed by Lower Jurassic beds, while the steeper crest and the plateau, the home of William Smith, consist of Middle and Upper Jurassic limestones, with considerable masses of clay. Oolitic beds (p. 110) are very common, and corals of modern aspect form broad banks and reefs.

The soft oolite known as "Bath Stone" belongs to the

Middle Jurassic series, and to the Bathonian stage; the still more famous building-stone from Portland is Upper Jurassic, and even French authors speak of the *Étage portlandien* in its honour.

The close of the period was marked in England by estuarine conditions, which gave us the Purbeck beds of Dorsetshire and Sussex.

The **Cretaceous** system will be dealt with in some detail in the next chapter, when we apply our mode of reading the annals of the earth to one especial district. It takes its name from the Latin *creta*, "chalk,"[1] since that soft white limestone is conspicuous in the upper series. The Chalk, indeed, spreads across England from the coast of Dorset to Cromer, and extends beyond the Wash to Flamborough Head. It forms a broad and rolling country, the very type of which is to be found in Salisbury Plain; its surface is bare, but for a few tree-clumps, and everywhere shows flecks of dry white rubble through the thin coating of brown soil. The white cliffs of Albion are a noble feature of our Channel coast, and are boldly repeated across the water by the similar masses at Dieppe.

And with the Chalk the Mesozoic era also closed. At its outset, we find a mingling of extinct and modern types of life. The Trias contains molluscan genera from Carboniferous and Permian times, side by side with others that are still living and prolific. The great group of cephalopods known as "ammonites" (fig. 29), with their coiled shells, and with greatly folded partitions between their internal chambers, commenced in the Permian of India and spread rapidly in the Trias. Some molluscan genera which are restricted in area and in number of individuals at the present day flourished abundantly in early Mesozoic epochs—for example, *Trigonia* among lamellibranchs and *Pleurotomaria* among gastropods. The most marked difference between Mesozoic times and our own lay in reality in the character of the vertebrates. The fishes had laid aside much of the bony armour that characterised them up to Permo-Carboniferous times; but the modern type of fish, with a fully developed internal bony skeleton, did not appear in force until the Cretaceous. Mammals came in, in a very humble way, in

[1] *Creta* was a white earth from Crete, an early example of a locality giving its name to a rock-species.

the Triassic period, and remained, strange to say, extremely subordinate, and of the lowest types, until the close of the era. The real lords of the Mesozoic earth were the reptiles, of which we shall see something in our researches among the Surrey Hills. These predominant animals were fairly high up in the scale of life, but were not remarkable for their brain-power. A few quaint birds have also been traced; so that all the great modern classes of life were represented.

The Mesozoic plants remained for a long time of lowly character; but a somewhat rapid change set in about the middle of the Cretaceous period. The flowering plants and modern trees then began quickly to replace the old conifers and tree-ferns, and for the first time wild-flowers added their colours to the landscape. Marked as was the advance in life-forms, if we compare the highest Cretaceous stage with the highest Permian, there were many changes still in store at the dawn of the Cainozoic era.

IV. The CAINOZOIC or "recent life" era is the only one that is divided upon a uniform and systematic plan. Sir C. Lyell, in 1833,[1] proposed a series of names based on the number of molluscan species which occurred both in the Cainozoic systems and in a living state in existing seas. He thus gave us a *Pliocene* system (*πλείων* and *καινός*, "more recent"), in the upper beds of which 95 per cent. of the molluscan species are also found living, while in the lower beds the proportion is 35 per cent. Below this comes the *Miocene* (*μείων* and *καινός*, "less recent"), with some 17 per cent. of living molluscan species; and at the base is the *Eocene* (*ἠώς* and *καινός*, "dawn of the recent"), with 3½ per cent. of living molluscan species. The German geologist Beyrich showed later the necessity for introducing a fourth system, the *Oligocene*, or "little recent," between the Eocene and the Miocene.

The whole of these four systems can be far better studied on the European continent than in their poor representatives in our own islands. Lyell, indeed, formed his classification after travelling in Italy and France, and with the help of the splendid collections then being made by French conchologists.

The **Eocene** system of the Paris Basin is, however, fairly repeated in the south-east of England, especially in

[1] "Principles of Geology," vol. iii, p. 53.

the Isle of Wight and Hampshire. The black-blue clays of the pits immediately round London provide us with a fair number of fossils, and there are hard beds formed by estuarine shells in the sands about Chislehurst and Croydon. As a whole, our Eocene strata are soft and yielding, and produce only rounded hills, the slopes of which are liable to earth-slips after heavy rains.

In the Inner Hebrides and north-eastern Ireland (p. 183), great volcanic eruptions broke out during Eocene times, the remains of plants that were growing on the land-surface becoming entombed amid the tuffs and lavas.

The **Oligocene** system is largely represented by fresh-water beds in Europe, with evidences of frequent incursions of the sea in the south-east and east. Professor Judd has shown how the beautiful series of strata that occupies all the northern half of the Isle of Wight is the equivalent of the Lower Oligocene of the Paris basin. The shells are estuarine, fresh-water, and even terrestrial, with a few marine bands, and the soft clays and sands make collecting fairly easy. The state of preservation and the distinctly modern type of these fossils give even the most casual observer some idea of the "Cainozoic" character of the deposits.

The Upper Oligocene is absent from our islands, as also is the whole of the **Miocene** system. The latter can be well studied in its three great marine series in North Italy and Austria, and in its fresh-water representatives, with a marine middle series, in Switzerland and France. The plant-beds of the British Isles, formerly regarded as Miocene, have now been referred back to the Eocene.

The **Pliocene** sea has, however, left its traces with us, notably in the east of Norfolk and Suffolk. Here, in sandy excavations, we may see, as it were, sections of some modern shelly beach (Plate X). It seems hard to believe that half the species of molluscs, which we can so easily extract from their soft matrix, have become extinct since the formation of many of these loose and current-bedded deposits. As we reach the higher series, this modern aspect becomes more and more striking, until we pass into the most recent geological formations, the "raised beaches" of the **Post-Pliocene** period.

A great epoch of colder climate, with a remarkable development of glaciers, and of floating ice in European

waters, set in at the close of the Pliocene period, and gave us our wide-spread "drifts," with their glaciated stones and their thick irregular beds of clay and sand. The later epochs of the Post-Pliocene pass into historic times, and the whole period corresponds with the existence of man upon the earth.

The opening of Cainozoic times showed at once the predominance of mammals. The humble creatures of the Mesozoic era now assumed an immense superiority and variety. Like the Permian and Triassic reptiles, they were adapted to a great range of food and habits, and some became specialised as vegetable-feeders, some as flesh-eaters; some took to the sea, in the form of great toothed whales, while others, as little bats, flew in the air. The reptiles with equal rapidity became narrowed down to their present restricted types; their empire had been utterly taken from them.

The older Cainozoic mammals were, however, widely different from any that we possess at the present day, and often combined the characters of two or more living genera. The humbler forms of life, however, such as the molluscs, closely resembled our modern types, and lamellibranchs and gastropods were in Eocene times already largely in excess of brachiopods. The ammonites, so essentially characteristic of the Mesozoic periods, had entirely disappeared, though their ancient ally, *Nautilus*, still existed. The plant-life also approximated to that of our own times, and honey-sucking insects are consequently found as fossils in Cainozoic strata.

The wonderful mammalian deposits of Provence and Greece,[1] and of the Siwálik Hills in India, show us how, even in Pliocene times, the highest forms of life were still strangely distinct from those of the Post-Pliocene and Recent period. The types that we now know were then represented by more gigantic forms, which waged war upon one another, until Man appeared among them. Here they met a creature capable of killing off the fiercest of them by superior art and cunning, and of leading the more docile into perpetual and even hereditary slavery. The exact period of Man's entry upon the earth may never become precisely known. The wonderful skull styled *Pithecanthropus*, found in Java by Dr. Dubois[2] in 1891, associated with ex-

[1] For a charming account of Cainozoic mammals, see Gaudry, "Les Ancêtres de nos animaux."

[2] *Trans. R. Dublin Soc.*, vol. vi. (1896), p. 1; and *Nature*, vol. liii. p. 115.

tinct Pliocene mammals, and the chipped flint-flakes recorded by Dr. Noetling from Burma, which are said to underlie 4620 feet of Pliocene strata, give us some idea of the oldest epoch at which we may expect to find remains of man.[1]

In any case, the base of the Pliocene is comparatively near us, while the commencement of the Palæozoic era lies some forty times as far behind us. Estimates may be made, from the thickness of the marine strata composing the successive systems, as to the relative time that elapsed during their accumulation. To convert these data into actual years seems beyond our present powers, though several calculations have been made, based upon the rate of accumulation near existing shores. Giving the Cainozoic era its fullest value, as displayed to us by the Italian deposits, we may allow it to have been slightly longer than the Mesozoic era; while the Palæozoic era was four times as long as the Mesozoic. If we start our annals at the base of the Cambrian, with a time-point which we will call 0, and divide a column representing subsequent time into 100 divisions, like the degrees on a thermometer, then we arrive at the following *approximate* results (fig. 24).

(i) The Palæozoic era extended from 0 to 64 degrees of our scale.
(ii) The Mesozoic era terminated at 80 degrees.
(iii) The Cainozoic era extended over the remaining 20 degrees, including the present time.
(iv) In this comparatively short time of 20 degrees, as we shall see for ourselves when we come to our final observations (Chapter X.), the most extraordinary changes went on in the surface-features of the globe, side by side with marked changes in the forms of mammalian life.
(v) The oldest remains of man are found at 99 degrees of our time-scale, or one unit only from its summit; while human "history," in the ordinary sense, even that of the Chaldæans and the Chinese, can only be represented by a minute fraction of a degree.

Here we are met, then, by the most remarkable and inspiring feature in the whole annals of the earth. Man, with all his pride of life and reason, is still, as it were, only

[1] For references to papers on this subject, see *Knowledge*, vol. xxii. (1899), p. 270.

upon the threshold of his career. All the enormous periods that have gone before, with their struggles between this and that class of living creatures, culminate in the Post-Pliocene period, with the predominance of a being who seems capable of controlling his own surroundings, and of forging out new lines of progress for himself. In view of the long past, beside which human history is absolutely insignificant, the differences between individual men seem indeed of the most trivial character; and we may look forward with confidence to the work which Man as a race may yet achieve.

We now see how much William Smith and his fellow-workers have added to the interest and value of our fossils. If we begin to examine any collection, we find that even fossils must first be studied in the open-air. We must not be content with the bringing together of chance specimens, preserved as curiosities by a past generation, or picked out of the rubbish of a lumber-room; we must collect intelligently for ourselves, sampling our district bed by bed, and comparing the general aspect of the fauna, when we return home in the evening, with the drawings and descriptions in the text-books. The determination of the exact species of a fossil is often a work of care and time, and we may have to visit our nearest scientific library, to refer to the figures prepared by the original author of the specific name. No one can be expected to carry the details of hundreds of fossils in his head; and too much attention is often given to the learning off by heart of lists of species, when a few lessons in zoology, and in the general characters of successive faunas, would far better fit a student for appreciating Nature in the field.

We are by this time not only armed with the means of assigning any particular fossiliferous series of strata to its correct epoch in the world's history, but we can also detect, through the evidence of fossils alone, the occurrence of any considerable unconformity. If we find, for example, Triassic fossils in a bed which rests upon one containing Devonian fossils, we know that the intervening Carboniferous and Permian beds were either swept away by denudation before the Trias was laid down, or were never deposited in this locality, owing to some upheaval that occurred at the close of the Devonian period. We must always remember that we may find a fresh-water and a marine type of every system, while estuarine beds elsewhere unite the features of the two, besides containing shells characteristic of brackish water.

In due time the history of the most complex district can be unravelled, and we learn how many processes of construction and destruction have been required to produce the surface-features that we see around us. "Stratigraphical geology" becomes, in fact, "Historical geology"; and any notes that we may make on the beds in a local section, and on the fossils that we discover in them, may prove to be a serious contribution towards the completion of the annals of the earth.

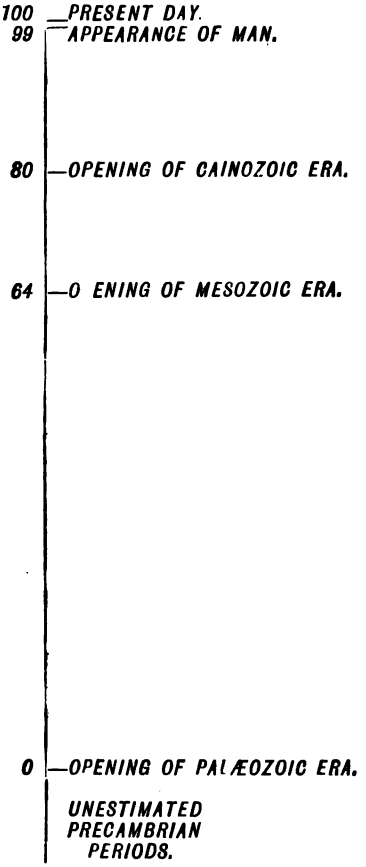


FIG. 24.—DIAGRAM OF HISTORY OF LIFE ON THE EARTH (see p. 241). The appearance of man is placed as far back as seems at present possible.

CHAPTER IX

THE SURREY HILLS

To apply the ideas gained in the last chapter to a special instance, we can scarcely do better than to visit the country to the south of London. There are few regions more simply beautiful, and few better known to the millions of dwellers in the south-eastern counties of England.

Whether we reach the hills of Surrey by the London and Brighton Company's Portsmouth line, or by the South-Eastern Railway to Red Hill, the features traversed are much the same. We pass the brown gravel cuttings in the suburbs, the oozy clay-banks towards Croydon, and then emerge upon an open rolling country of dry chalky fields, leading up to clumps of little woods; the church-spires set among them upon the rising ground show where the old villages have clustered. There is a steady incline from London southwards, until we reach bolder hills with white chalk cuttings through them; and at last the railway has to tunnel through a ridge, at Mickleham in the one case and at Merstham in the other. When we come out into the air again, we find ourselves leaving the face of a fine green range; a lowland, well wooded, with ponds and brickyards scattered in it, stretches for a few miles before us; and then the ground rises again in the distance towards broken and fir-clad summits.

If we reach Dorking, we can climb the highest point in the area, and make our survey from it, as we did from the Puy de Pariou in Auvergne. Five miles south of the town, Leith Hill rises, 967 feet above the sea; and we make our way through the forest-land towards it, with a singular sense of freshness after the traverse of suburban London.

From the summit we look over into several counties, including the whole of Surrey and its hills. Nearly all Sussex lies before us, and the borders of Kent are in the east. The features immediately around us are repeated, moreover, in

these three counties, wherever we come to the edge of the great chalky uplands.

If we begin by looking north, we see a wide country, almost a plain, with a few flat-topped hills rising above it in the west, and one or two rounded summits far away in the north-east. On one of the latter, best seen at sunset, the Crystal Palace has been planted. Smoke and thick air hide the limits of this view; but on a summer evening we may see the towers of Westminster, rising faintly in pink haze, and marking out the site of London.

This is the area over which we rose slowly to the chalky plateau; and we are really looking down the south slope of the valley of the Thames. On the near edge of this region, the ground falls abruptly towards us, forming the long range of the North Downs, the surface of which is here ploughed over, here covered by thin yellowish grass, here broken by a great white quarry or a deep groove filled with trees. The brow of these hills is often marked by beech-woods, and we again see the church-spires along the edge, showing the position of high villages. Through one conspicuous gap, the River Mole wanders northward to the Thames, while Dorking is built upon a tributary which descends to join it from the west.

At the foot of the sudden fall of the surface, there stretches a long band of low-lying meadows, through which this tributary takes its course. Then follows the rise to more broken country, and fir-woods climb towards us up to the very ridges of the hills on which we stand. This zone of the landscape is given over, indeed, to forest and to heather; and Leith Hill itself is its culminating summit.

The view southward is, however, far more striking. We are on the very edge of a second range of hills, nearly twice the height of those that lie north of us; on the west, in particular, the projecting masses of this range run out like promontories into the plain below. Far away, the curved front of these hills is continued by the long purple slope of Hindhead, the southern face of which also falls steeply into the lowland. The tops of all these promontories are formed by gently sloping plateaux, dipping towards the first range in the north; the fir-woods cover these, and stretch in part over the steep southern side, shading off there into thickets of beech and oak and underwood.

Below us is the pleasant country of the Weald, the old forest-land that for long presented difficulties to the invading Normans. Now it is in great measure cleared, and cut up into green pastures, with ploughed fields here and there. The roads and villages are marked by bands of elms, and large ponds gleam below us in the sunlight. Away in the east the great curved back of Ashdown Forest rises, dark with firs, out of this softer cultivated region.

The Weald immediately in front of us knows no such interruption. The fields and hedge-rows stretch away for some sixteen miles, until they reach the foot of a row of hills which are somewhat hummocky and irregular. In August we may see on these, even at this distance, the purple of an almost continuous expanse of heather. But they are at times difficult to pick out against the slopes of a far bolder range that rises immediately behind them. Grey and distant, the South Downs there assert themselves as a long wave-like ridge on the horizon, with the beech-clump on Chanctonbury Ring standing out darkly and distinctly, 800 feet above the sea. One or two deep notches show us glimpses of lower ground beyond, and on clear days the English Channel is visible in the gap at Shoreham.

A telescope will soon reveal to us how the nearer and humbler range of hills sweeps round on the west to join the long mass of Hindhead. The South Downs similarly disappear on that side into the rolling plateau of Salisbury Plain. The North Downs, which are continued beyond the gap at Guildford by the narrow ridge of the Hog's Back, also pass into this plateau, and are thus connected with their bolder southern rivals. Thus this end of the Weald is hemmed round with two approximately parallel ranges, the outer one bare on the whole, with short grass and a few beech-clumps, the inner one more broken, and dark with the broad masses of the fir-woods.

The actual junction of the inner ridges, as they approach one another from north and south and unite at the western extremity of the Weald, is clearly seen in Harting Combe, six miles south-west of Haslemere. We descend by a rough sandy road from the high common into a narrow valley, which we cross close to its head. Here on three sides we are hemmed in by steep banks, covered with trees, while on the east side we look out into the broad Wealden hollow. In a

few minutes we are climbing the opposite ridge, to an open heath similar to that upon the north. And then the view of the South Downs, rising picturesquely before us, with a line of villages in the lowland at their foot, repeats in all its essential features the view northward from Leith Hill.

This regularity of features on both sides of the Weald must have some similarity of structure underlying it. If we study the ridges in detail, we soon see that the outer and the inner are composed of very different materials. Even from the summit of Leith Hill, we can perceive the series of white chalk quarries all along the face of the North Downs. They commence at a certain height up on the slope, which suggests that another material underlies this pure white limestone. Beyond Dorking, the Mole, excavating its channel against its eastern bank, has produced a fine natural exposure, the slope of Box Hill being there too steep for anything but a few clinging bushes. The white crumbling surface appears almost as a cliff, while woods of box and beech are massed above upon the plateau.

But the forest-range, the dark jutting masses culminating in Leith Hill, show yellow sandstone in every section. The roads are paved with yellow blocks, the cuttings are yellow, and are often penetrated by the holes of sand-martins. What, then, is the relation of these two types of strata to one another?

Sections taken very near the surface may be misleading, since the higher parts of slopes always tend to creep downwards, and there is in all such cases considerable shifting, even of the more solid deposits, by the action of gradual land-slides. But, if we take the evidence of a number of the deeper cuttings, such as we get in the beautiful lanes leading northwards through the fir-woods, we shall see that there is a steady slope of the beds towards the hollow between the Leith Hill range and the North Downs (fig. 25).

The angle which uptilted strata make with a horizontal plane is called their **dip**; more precisely, the dip may be defined as the greatest angle that can be made with the horizontal plane by a line drawn in the surface of the stratum. If an exposed surface of the bed were perfectly smooth, water poured on it would run down in this direction of greatest steepness; the line marked out by the water would also indicate the direction of true dip; a vertical plane passing

through it would point either north, or south-east, or so forth. When we say that a bed dips 15° to the north-east, we mean that it slopes down most steeply towards the north-east, the angle made by its surface and a horizontal plane being 15°. Or, to put it another way, if a vertical quarry-face were carved out of this dipping series of strata, this face running N.E. and S.W., the strata would fall towards the N.E. end of the section, and the lines of stratification would meet the horizontal floor of the quarry at an angle of 15°.

In determining the amount of disturbance of strata, and their relations to one another, we require some instrument to accurately indicate the dip. If our quarry-section or natural cliff does not lie in the direction of *true dip*, the angle observed will be smaller than that required; and the largest of a number of *apparent dips* thus collected will be nearest to the true angle. It is easy, however, to make a geometrical construction to determine the true from any two apparent dips.[1] Where a large smooth surface of a stratum is exposed, the direction in which a cutting must lie to display the true dip can be found as follows:—Take a spirit-level with a fairly long base, and move it about on the surface until the bubble becomes central. Place a walking-stick, resting on the same surface, perpendicular to the straight edge of the spirit-level. The stick lies in the direction of greatest steepness; it shows to what point of the compass the bed dips, and the complement of the angle between it and another stick held vertically at its lower end would give us the amount of the true dip.

To measure the dip in any section, a **clinometer**, or "inclination-measurer," is required. This can be very simply made. Draw a semicircle on cardboard, with a radius of about 6 centimetres, and divide it, like a protractor, into 180 degrees. Place the base upwards and number the lowest point of the curve 0°, and continue the numbering up to 90° on either side, the two points marked 90° being thus on the base-line of the semicircle. Glue the card down on to a flat well-squared piece of wood about 20 cm. by 8 cm.; the top of a cigar-box provides good material. The base of the semicircle must be near to and accurately parallel with one of the long edges of the wood. Then press a draw-

[1] See "Aids in Practical Geology," p. 6; and W. H. Dalton, *Geol. Mag.*, 1873. p. 333.

ing-pin nearly home into the wood through the centre from which the semicircle has been described. Hang a dark thread, by a loop at one end, from the drawing-pin, and attach a small weight to the other end, so that it hangs freely below the semicircle when the long edge of the instrument is held horizontally. The clinometer is now complete.

To determine a dip, stand some seven or eight yards from the face of the section, and hold the clinometer in a plane parallel to it. Then adjust the long top-edge until it appears to coincide with the exposed edge of one of the strata. The pendulum, formed by the weight and thread, of course still hangs vertically, and the reading where the thread crosses the arc shows how many degrees the edge of the stratum

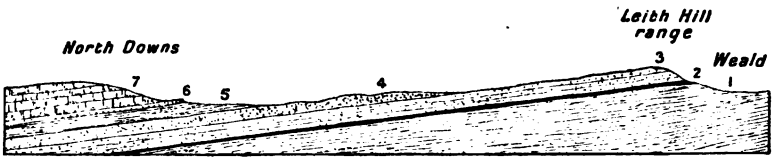


FIG. 25.—SECTION ACROSS THE SURREY HILLS. VERTICAL SCALE NEARLY THREE TIMES THE HORIZONTAL.

1, Wealden Beds; 2, Atherfield Clay; 3, Hythe and Bargate Beds; 4, Folkestone Beds; 5, Gault Clay; 6, Upper Greensand; 7, Lower, Middle, and Upper Chalk.

deviates from the horizontal. The direction of the face of the section is obtained with an ordinary compass.

The dips of our Leith Hill sandstones are found to be but small, 5° being common; but that is quite sufficient to bring them, if continued northward, well under the ridge of the chalk Downs. Indeed, in the distance of four miles, and with their relative heights, a dip of 2° would do so. If we examine in turn the quarries of the soft white limestone known as chalk, which we find forms the mass of the North Downs, we see that this series of strata also dips northward at a similarly low angle. Away in the Hog's Back, between Farnham and Guildford, the dip rises to 40°; but this is quite exceptional for the Surrey Hills.

Following out these observations all round the Weald, we

find the dips becoming N.W. near Farnham, then W., and finally S., as at Harting, and Arundel, and Brighton. The beds have been bent, then, into a flattened ellipsoidal dome, something like the roof of a great elongated public hall. One end of the dome lies in Salisbury Plain, and east of this the top has been worn away, the two most resisting layers of which it was composed standing up to form the ridges round about the Wealden area. Such ridges are called **escarpments.** For their production we must have strata more or less inclined (fig. 25); the weathering eats its way along one of the sloping surfaces between two beds or series of beds, and cuts back the upturned faces of the beds lying above this plane. The ground at the foot of an escarpment is thus formed by the dipping surface of the underlying series of strata; the face of the escarpment is formed by the joint-surfaces of the overlying series, which allow the rock to weather down steeply, the slope being of course only in rare cases a vertical cliff, and being usually banked over with long taluses. The back of the escarpment is formed by the dipping surface of the beds which have given rise to it, and from which some other series of strata has probably been removed.

The ridges formed by the upturned edges of the beds that we crossed on the sea-shore (p. 92) are excellent models of escarpments. The dipping surface between the edge of one escarpment and the foot of the next is called the **dip-slope,** and is usually, in examples on a large scale, inclined to the horizon at a slightly less angle than the strata themselves.

While escarpments may be worn out, even where the successive upturned strata are of equal hardness, by the giving way of the rock, block by block, along its planes of bedding and of jointing, yet on a large scale in nature their formation is greatly facilitated by the occurrence of a hard or a tough resisting bed above one more liable to be worn away. The general tendency of denudation is to wear down the surface evenly; but the exposed edge of the soft bed is cut down more rapidly, the more resisting one standing out above it as an escarpment. Rivers will flow in such cases in the hollows thus worked out, approximately at right angles to the direction of dip of the strata, and will continually undercut and perpetuate the escarpment. Their tributaries will flow down on one hand from the underlying dip-slope,

and on the other from the steep face of the escarpment. The dip-slopes will thus be channeled by subordinate valleys, the streams in which run parallel to the direction of the dip; while the escarpments will be cut back into combes by streams parallel to the foregoing, but running in the opposite direction, *i.e.*, away from the point towards which the beds are dipping. Between the action of the main stream in the hollow and the tributaries in the combes, the face of the escarpment is continually receding in the direction of the dip, while it comes to have a picturesque wavy form, owing to the hollows locally carved out in it by the tributaries.

There is one direction, and only one, in which a horizontal line can be drawn in the surface of an uptilted stratum. That direction is called the **strike**, from the German word *Strecke*, meaning the "stretch" or "extension" of the bed. This line is perpendicular to the direction of the dip; and it is clear that the general trend of an escarpment will be in the direction of the strike.

If the strike of a bed varies, the direction of dip must vary also, its amount remaining or not remaining the same. If the direction of dip remains the same, but its amount varies, the strike remains unaltered; but it must be noted that beds dipping in exactly opposite directions have the same strike. A horizontal bed may be regarded as striking in all directions, or as having no especial strike.

We have seen how the northern escarpments in the Surrey Hills are repeated away in Sussex on the south. The long blue bands that lie there facing us are the opposite limbs of a great fold, which is five-and-twenty miles across. Every escarpment must thus, at some time or other, have had its continuation in some opposite slope. Possibly the strata may have been bent over into a horizontal position, and may have so extended for some distance; but eventually they must have sunk on the other side approximately to the level that they occupied in the crust before the formation of the fold. An upward fold of this kind, the ridge of which may be sharp or broad, is called an **anticlinal**, from the fact that the beds dip in opposite directions on either side of the ridge; while the corresponding fold, in which a trough is produced, is a **synclinal**, the beds sloping towards one another and forming the floor of a depression as they meet (fig. 36). In folded strata, as we shall see in the next chapter,

anticlinals and synclinals may follow one another in quick succession.

Thus the dip of beds may vary in amount, and may reverse itself in direction, again and again in a short stretch of country; and then the general lie of the strata is best described by saying that they are repeatedly folded, but that they *strike* in such and such a direction.

If we keep in mind what we have before our eyes in the west end of the Weald, we shall never forget that an anticlinal mass is not quite so simple as it appears when we draw a diagrammatic section across it. It must have a termination somewhere on this spheroidal earth; there must be a point where the beds will dip down outwards in a constantly changing direction, until we get round to the other main flank of the anticlinal. That is the feature presented to us at Harting Combe. If we have strata pushed up as a mere dome, like that of a cathedral, any one bed will dip outwards in all directions from the apex of the dome formed by it. An anticlinal mass is merely such a dome greatly extended in one direction; and this dome-like character will be obvious at the two ends of the fold, which may be a few yards or many miles apart.

If the action of denuding agents has planed a smooth horizontal surface across a set of tilted strata, the area occupied by each bed on the surface will depend upon the angle of dip (fig. 26). If the dip is vertical, or 90°, the width of the band formed by a bed on the surface is equal to the thickness of the bed; but it widens out as the bed dips at a lower and lower angle. The extreme case is where the bed becomes horizontal, when it covers the whole level surface, concealing the other strata beneath it. Hence, the more nearly horizontal a bed is, the more we see of it in traversing a level country, and a thin layer of rock may then often seem to have a great importance.

The area of a bed exposed at the surface of the earth is called its **outcrop**; and the extent of this will be similarly affected if the beds are horizontal and if the surface formed by denudation cuts across them (fig. 26). On the face of a cliff formed in horizontal strata, the true thickness of each bed is seen; on the gently sloping sides of a valley, the outcrops become far more extensive.

Thus the outcrop of a bed depends on its dip and on the

angle and direction of the denuded surface; a bed may, for instance, by reason of its dip, emerge perpendicularly to the face of an escarpment, in which case the width of the outcrop is of course again equal to the thickness of the bed.

Here we have the secret of the difference between the narrow ridge of the Hog's Back near Guildford and the typical broad plateau of the Downs. The steep dip in the former region (p. 249) enables all the thickness of Chalk to appear in the limits of a narrow outcrop, the dip-slope being at least as steep as the face of the escarpment; while

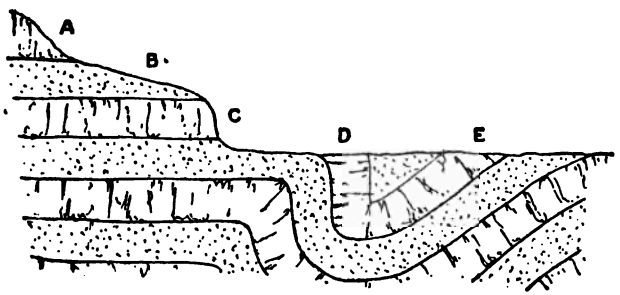


FIG. 26.—SECTION ILLUSTRATING VARIATION OF WIDTH OF OUTCROP WITH SLOPE OF SURFACE AND DIP OF STRATA.

The beds are all of the same thickness, but the outcrop of B is far wider than that of A or C, although the three beds are horizontal. The outcrop of the bed at E is wider on the same horizontal surface than at D, owing to a lessening of the dip.

the very low average dips in the ordinary North Downs spread out the outcrop over a width of many miles.

Another striking feature of our Surrey landscape demands an explanation before we study the beds in detail. The River Mole seems to defy the physical structure of the country. It rises in the fairly low ground of the northern Weald, where its higher tributaries wander down from the slopes of St. Leonard's Forest, and bring with them a good burden of clay and sand. But at Dorking it meets and cuts through the Chalk escarpment, making a valley 300 feet deep, and then flows rationally down the dip-slope towards the Thames at Ditton. All the great streams of the district follow this

strange example, and both the North and South Downs are cleft by steep-sided valleys. Instead of draining eastward, under and along the faces of the escarpments, the Weald sends its waters north and south directly across the ridges of the hills. We can thus see the gap of the Wey near at hand at Guildford, and before us the notches of the Arun and the Adour, deeply indenting the dark sand-ranges and the South Downs. The water cannot have run up the faces of these escarpments and then have carved its way down to its former level; the only probable conclusion, from a careful inspection of the country, is that the rivers are older than the escarpments.

They began to flow, in fact, when the great anticlinal of chalk was first lifted above the sea, and when its ridge was first attacked by denuding agents. The main drainage-lines would thus naturally lie down the dip-slopes to north and south. Gradually the tributaries of these main streams, working between the harder and softer strata, began to cut out the east-and-west escarpments; but the valleys which were already excavated down the dip-slopes prevented these new ridges from being continuous, and the yielding materials that fell a prey to the lateral streams were still swept out of the district by the north-and-south main routes.

If one of the streams cutting across the strike, *i.e.* traversing the escarpment, worked its way down more rapidly than another,[1] the drainage falling into it on the Wealden side would increase in importance. More water, that is to say, would flow into the greater depression. Its tributaries, parallel to the escarpment, might work back and back, "capturing," as the phrase goes, the head-waters of other streams that crossed the escarpment. These latter streams would then dwindle, and even in time cease to flow, since the active tributaries in the Weald, now united in one system, would lower the general level of the ground, until no more water could get through the notches cut by the smaller transverse streams. This tendency to reduce the number of streams across the escarpments is seen in the waterless valleys that occur on the back of the Surrey Downs. Above Godstone, for instance, the old northward-running river of the Caterham valley had already, at the time of its

[1] See W. M. Davis, *Geographical Journal*, vol. xiv. (1899), p. 429, and other papers.

extinction, cut a valley 250 feet deep across the ridge. It is fair to observe that an increase in rainfall on the Downs might now lead to a reversal of the process, to the cutting back of the valley-head, and to the capturing of some of the eastward or westward flowing waters on the Wealden side of the escarpment (compare p. 85).

Thus, by deep scorings of the dip-slopes, and by a general scouring out of the beds in the heart of the great anticlinal, the beautiful variety of landscape that spreads before us has been produced. The very core of the Weald is formed by St. Leonard's and Ashdown Forests, where sandy strata, the lowest of the folded series, are exposed. The anticlinal movement has brought them, at Crowborough Beacon, 800 feet above the sea; but at our west end they are sunk below a series of clays which form far less bold a feature. It is time now to descend the face of Leith Hill, and to leave the wild heath and forest for these cultivated lands. In the roadside cuttings and the Wealden brick-yards we can begin to study the course of events that occurred before Surrey and its hills were dreamt of.

The general assemblage of fossils, which have been diligently collected in this district throughout the nineteenth century, shows that the Weald and the surrounding ridges are alike formed of Cretaceous strata (p. 231). In the **Wealden series** we have the base of the system, and, in fact, a passage down into the true Jurassic beds, which peep out directly under them in the neighbourhood of Hastings.

The lower beds of the Wealden dome are mainly sandstones, forming loose sandy heaths near Tunbridge Wells, across which it is impossible to make permanent cart-roads. In a few gritty bands and clays associated with them, fresh-water fossils have been found. The spirally coiled univalve mollusc *Paludina* is perhaps the most noticeable; it still lives abundantly in rivers and in inland seas in all quarters of the globe, and whole beds of limestone, such as the "Sussex Marble," are made up, in the Wealden series, of its remains. The little spiral shells are well seen in section when the rock is sawn and polished; and the famous "Purbeck Marble," used so largely for the shafts of small columns in our cathedrals, is a similar stone from the uppermost Jurassic strata.

A few bivalves occur, of genera that typically inhabit

fresh or brackish water; their presence supports the view that these beds were formed in the broad waters of a lake.[1] A number of fish-remains have also been found; but the most remarkable back-boned animals of this epoch were undoubtedly the gigantic reptiles.

In 1822 Dr. Gideon Mantell discovered certain teeth in the sands near Cuckfield in Sussex; and he named the animal to which they belonged *Iguanodon*, since, in their flattened form and saw-like edges, they resembled the teeth of the living South American reptile *Iguana*. It often happens that a name must thus be given to fossil remains before any considerable portion of the animal is discovered. In 1834 a number of large reptilian bones were found at Maidstone, together with the cast of a tooth and the fragment of another[2] similar to those already known; and, later, detached bones were found all through the Wealden deposits. The animal was now known to be a formidable creature, although vegetarian in its habits. More recent discoveries of the same genus in Belgium have shown that it was from eighteen to thirty feet in length; its hind legs were longer and altogether more powerful than its fore legs, and it walked fairly upright upon them, dragging its huge tail behind it on the ground.

There were other genera of reptiles also in Wealden times, including crocodiles; and among the largest was *Megalosaurus*, which was a flesh-eater, judging from its teeth. This creature was about twenty-five feet long; but *Cetiosaurus*, a vegetable-eater, surpassed it, some species being nearly forty feet long. The Wealden *Cetiosaurus* is only known, however, by a few bones, mostly separately scattered in the deposits.[3]

The trees surrounding the lakes and rivers were far different from those prevailing now-a-days in the Weald. Not a beech, nor an elm, nor an oak existed, as far as we know, upon the surface of the earth. There were forests of conifers, like those now massed darkly on Leith Hill, and tree-ferns grew,

[1] See A. Jukes-Browne, "The Building of the British Isles," p. 268.

[2] Mantell, "Medals of Creation," 2nd edit., vol. ii, p. 691; "Wonders of Geology," 6th edit., vol. i, p. 422; Hutchinson, "Extinct Monsters," pp. 82–89.

[3] For the variety of these reptilian remains, see R. Lydekker, "On a New Wealden Iguanodont and other Dinosaurs," *Quart. Journ. Geol. Soc.*, vol. xliv, p. 46; and for a general account, with restorations, see H. N. Hutchinson, "Extinct Monsters," pp. 59–108.

picturesquely spreading, on the river-banks. A group of comparatively short and thick-stemmed trees, the Cycads, unknown to us now in a wild state in Europe, abounded then throughout England. They are allied to the conifers, and are thus regarded as low and humble among the flowering trees; and at present they have to be imported from the tropics. All these plants are represented by stems and leaves washed into the beds of Wealden clay and sandstone; and the frequency of patches of lignite is another piece of evidence in favour of the fresh-water origin of the Wealden strata.

The higher beds, which spread before us from the foot of Leith Hill, and which, indeed, form much of the bulk of the range itself (fig. 25), are composed of a fairly pure clay, sometimes 1000 feet in thickness. The surface is often damp, and oak-thickets abound upon it; the roads running through these woods are sloughs of despond after heavy rains, and the pathways in more frequented districts are raised upon causeways to keep them above the level of the floods. The brick-yards show us brown and blue sections in the clays, often variegated by red and almost crimson stainings. These colourations, due to hydrated iron oxide, are also a character of lake-deposits (p. 142). On the surfaces of some of the more shaly beds we may find white relics of univalves and bivalves, like those in the clays among the lower sandstones; and tiny ostracod shells, looking like little split seeds, cover large areas characteristically. The ostracods are simple crustaceans which live in bivalve shells of their own making; and the detailed examination of the Wealden genera shows that many agree with those living in fresh water at the present day. Others, however, are extinct, and are thus useless for indicating the character of the Wealden waters.

All through the Wealden series, beds of sandstone cemented by rich brown limonite, or nodules of iron carbonate and oxide in the clays, have been dug out in former times for iron-smelting. As long as coal and iron ores were but little worked in the north of England, and as long as wood was freely available for fuel, this work went profitably forward; and now and again we may turn up the old slags from the furnaces, like fragments of volcanic glass, in some forsaken corner of the woodlands. From the thirteenth century to 1828[1] the Wealden iron was extracted; and the discovery of

[1] H. B. Woodward, "Geology of England and Wales," 2nd edit., p. 361.

coal in deep borings at Dover may some day again convert this garden of England into a fuming industrial centre.

Once more we have in these iron-ores an indication of lake-deposition, limonite being produced freely in such waters (p. 142), and soluble salts of iron being always present among the materials brought down from wooded shores.

Away in Dorsetshire, east of Lulworth, red and yellow clay-beds occur between the Jurassic limestones and the Chalk; and these mark the westward prolongation of the ancient Wealden lake. Its east end lay beyond the present Channel near Boulogne. So we may picture some 170 miles by 50 covered at the dawn of Cretaceous times by an inland sea, the floor of which sank as successive sand-banks and mud-banks were spread out in it. Plants of humbler groups, partly tropical in character, formed a kind of jungle on its banks, dense enough to provide food for the massive Iguanodons, which stalked about heavily and unhindered, their heads fifteen feet in air. Every now and then a crocodile snapped at the fishes among the leafy islets, half hidden by the natural rafts of fallen stems; while a Megalosaurus, looking out for some of the smaller quadrupeds, crashed through the jungle and left its footprints in the yielding swamp. Beetles hummed and crawled among the bushes; but none of our flowers, and none of our honey-sucking insects, enlivened the borders of the lake.

Slowly the sea began to creep in over the land, and the great lake became a tidal estuary; marine shells, including oysters, took up their abode in it; and the final muds of the Wealden stage contain a distinctly salt-water fauna. The bed above, the Atherfield Clay, is the first of a new series, which ushers in a long epoch of steady depression of the land.

So far we have pictured the reptiles as lords of the Wealden world. Birds must have existed, but their bones have not yet been forthcoming; such light remains would easily become scattered and broken up, and probably only a few individuals actually dwelt in the more secluded corners of the forest. The earliest known bird comes from the higher Jurassic strata of Germany, and is represented by two winged skeletons and an isolated feather. But for the feathers on the wings and tail, the creature might have been regarded as a reptile. For at this time the reptiles had also taken to the air; the whole empire of the globe seemed open to them, and

they grew huge and ponderous, having little need of exceptional intelligence to keep their predominance secure. No rivals seemed to threaten them. Some marched across the land, browsing on the tops of the cycads and tree-ferns; others, with long necks and cruel teeth, pounced down upon smaller creatures, crushing them with one stroke of their massive feet; others took to the sea, just as the mammalian whales did in later times, and became beautifully modified to suit their new surroundings, grasping, either by length of jaw or the sweep of a swan-like neck, the fishes that had long been secure from the attacks of higher beings. And other reptiles, again, provided with membranous wings, which were stretched from the enormously long outer finger of each fore-limb to their sides, flew through the air, and clung with claw-tips and wing-tips, like bats, to the faces of the crags. The earliest birds, as we have said, closely resemble feathered reptiles, and it is scarcely surprising that they also should have been armed with teeth. Probably they prevailed against the flying reptiles mainly by their power of more rapid and prolonged flight, and often, having hidden themselves from a pursuer in some dense-leaved tree, were disturbed again by the head of a prowling reptile looking down on them as he strolled across the forest. The voices of a flock of toothed birds, rising clamorously from the mud-flats of the Wealden lake, can hardly have been pleasing to the ear. Their long jaws would gape, showing the sharp teeth, like those of crocodiles; their feathered wings and tail would seem quaintly contrasted with their downy or almost naked bodies; and only their more elegant movements in the air would show what a step forward had been made in the great line of animal life. As we cross the pastures and copses of the Weald in spring, when every bank is starred with primroses, and every bush seems to leap with sparrows, and linnets, and cheerful chaffinches, it is hard to think of the same region in early Cretaceous times, when birds were few and of strange and forbidding types, and when all this carpet of delicate flowers was as yet unknown in the wide world.

In the United States, Cretaceous birds are known, later in date than the deposits of the Weald; it remains for some happy observer to turn up a bone or two in south-east England as a link between these and the specimens from the Jurassic beds of Germany.

We are equally ignorant regarding the highest animals, the mammals, of the period. The higher Jurassic beds of Britain have yielded jaws and teeth; the uppermost Cretaceous rocks in America have shown similar remains; and all we know is that the mammals of the Weald must have been of lowly character, humbled and kept under by the overwhelming power of the reptiles, and seeking their food by stealth almost between the legs of these great beasts. They must have been about the size of rabbits and foxes, with a considerable variety of teeth and modes of feeding; and we can picture them scuttling into their holes and lairs among the underwood, whenever the neck and chest of a great lizard began to sway the fronds of the tree-ferns. A certain quickness of apprehension, and ingenuity in the face of danger, must have been born in them during these long years of repression; and in later times, when the reptilian empire became doomed, the mammals naturally stepped into the gap, speedily ran riot across the jungles and the plains, and even entered the expanses of the sea. In Wealden times, however, they were of the humblest character, belonging to divisions at least as low as the monotremes and the marsupials, which zoologists place at the very bottom of the long series of existing mammals.

With the deposition of the **Atherfield Clay**, the Wealden area was invaded by the sea; and this stage is named from a spot on the south side of the Isle of Wight, where the beds are admirably fossiliferous. In the Wealden area, they form a portion of what we have called the sand-range, since they are protected by the more resisting beds above, and the front of the escarpment is cut down across them; but they naturally produce a more gentle slope than that given by the yellow sandstone. Above this stiff blue clay come the **Hythe Beds**, named after a Kentish watering-place. These are fairly firm sandstones, with grey shelly limestones among them as we go eastwards into Kent. In the Leith Hill area they seldom contain fossils, and we have to trace them over long distances before we can find a satisfactory fauna. A few plants were still being washed in from the land, and there are thus at intervals soft black-brown beds of lignite. The rock is quarried into for road-metal, and is seen in all the shallow pits which form patches of yellow through the dark woodland of Leith Hill. The

roads that cross the ridge are also bounded by little sandstone cliffs, in which the stratification can be seen. East and west, the bold escarpment of the Hythe Beds stretches, the finest feature of south-eastern England; and, as we shall presently see, it owes its origin mainly to the humbler organisms that lived in the Cretaceous sea.

The superior resistance of the Hythe Beds to denudation is, in fact, largely due to the numerous beds of flint[1] that are contained in them. In these beds the sand-grains are

FIG. 27. — SAND WITH NUMEROUS SPICULES OF SILICEOUS SPONGES, HYTHE BEDS, SURREY.

h, *l*, *t*, spicules; *s*, sand grains; *g*, dark grains of glauconite. × 40.

cemented by chalcedony, forming a brownish translucent rock of smooth fracture; the flint-layers thus constructed run along the stratification-planes, with more friable and pale yellow sands between them. Here we can pick up a fragment with three or four flint bands in a thickness of two inches; and in some of the little quarries we can choose

[1] These are commonly called "chert," but it is impossible to make any distinction between this material and flint. The Upper Jurassic nodular "cherts" of Dorsetshire, for instance, are precisely like the "flints" of the Upper Chalk.

large specimens which look like a pure pink-brown chalcedony throughout.

Down near Friday Street, for instance, some of the rough tracks through the forest are paved with translucent flint, just as some of the roads north of the Auvergne puys are paved with agates from the mines. If we look at these with a lens, we see an immense number of delicate white rods in them, reminding us of crystals in a glassy rock. These are the dull casts of sponge-spicules, which themselves originated the flint.

Our common modern sponges, such as we use in washing, have horny fibrous skeletons; but others, like the beautiful "Venus's flower-basket," make their meshy skeleton of silica; others, again, strengthen themselves with rods and three-rayed stars of calcium carbonate. Sponge-skeletons are built up of minute rod-like or often knotty bodies known as *spicules*, which frequently fall apart after the death of the animal and are scattered over the sea-floor. In many cases, moreover, this distribution is made easier by the fact that the spicules are only loosely interlocked to form the skeleton, or are merely embedded separately in the substance of the sponge. *Sponge-oozes* are made up at the present day of such remains. The siliceous spicules (fig. 27) are composed of amorphous silica, and not of quartz, and in this condition are liable to subsequent attack by the solvent action of the sea. The rod-like forms are traversed by tiny canals, so that they resemble, when broken, pieces of fairy thermometer-tubes; and the water slowly rounds the ends of the fragments and enlarges the central canal, finally dissolving the spicule altogether. Thus sponge-beds, like parts of coral-reefs and shell-banks, are removed in solution; but the material, wandering in the water near the ocean-floor, may be again chemically deposited and may consolidate as beds of flint.

The complete solution and re-deposition, however, probably do not occur until the sponge-bed is covered over by other sediments and becomes subject to the slow attack of the waters that permeate the earth's crust.[1] These waters,

[1] The rare cases in which silicification has gone on in modern oozes seem attended with the production of silicates rather than of opaline or chalcedonic silica. See "Report on Deep Sea Deposits," *Challenger Reports*, p. 390, and pl. xi.

moving along the bedding-planes of the strata, spread out the silica into more or less regular bands.

Sponges are by no means the only organisms that extract silica from sea-water; and we must expect to find remains of radiolarians, and of the tiny skeletons of the plants called diatoms, associated with beds of flint. As a matter of fact, however, solution has generally been pretty effective, and we have only the dull earthy moulds of sponge-spicules left to us, these spicules being bodies of comparatively coarse dimensions. The original substance of the spicules, and probably also of associated diatoms and radiolarians, is seen in the chalcedony round about the spicular casts.

These little rod-like relics are well worth looking for in the "cherty" layers; the silica has also enclosed the sand-grains and any other solid bodies that were in the stratum. We shall presently see, on the bare front of the North Downs, how silica is deposited with somewhat different results in the heart of massive limestones.

All the sandy layers of the Hythe Beds are "Greensands" (p. 107); and the prevalence of grains of glauconite (fig. 27) in these and in the overlying strata has caused the whole of the stages from the Atherfield Clay to the top of the Folkestone Beds to be called the "Lower Greensand," a name by which they are often known on maps. The glauconite grains give a dark speckly character to the rock, and come out as brilliantly green oval spots in microscopic sections. When walking through the Surrey lanes on a damp day, we may strike our hammer into the sandy wall of some roadside cutting; and the soft glauconite becomes crushed and spread out, so that the mark left by the hammer appears distinctly green.

Glauconite indicates, if we may judge from existing seas, that these sandstones were deposited in water fairly near the land. The beds are sometimes composed of coarse sand-grains, and we shall find real pebbles nearer Guildford; while the current-bedding also points to a shallow-water origin. The most interesting deposits are those at the top of the Hythe Beds, where a rough limestone, the **Bargate Stone**,[1] occurs. Besides marine shells, including foraminifera, such as lived on the Cretaceous beaches, we find this rock full of rolled fossils

[1] For recent work on these beds see F. Chapman, "The Bargate Beds of Surrey," *Quart. Journ. Geol. Soc.*, vol. l, p. 677.

derived from Jurassic beds. The dark little grains which are so frequent in the Bargate Stone prove to be wave-worn fragments of casts of molluscan shells, belonging to the preceding period. Oolitic grains, brought in from Jurassic limestones, spines of sea-urchins, and pieces of older flints, are found mixed together in this deposit. We have, indeed, to be careful in distinguishing the rolled and derived fossils from the remains of the animals that were living when the limestone was accumulated.

Such a discovery gives us at once a picture of the coast on which the Hythe and Bargate beds were formed. No Jurassic rocks now appear in this area; but they have been found at a depth of 1150 feet below the surface in a boring made at Richmond in the north of Surrey. They come out, again, from under the Cretaceous "greensands" at Oxford and Swindon on the north-west, and under the Wealden clays in the Isle of Purbeck. From a boring near Hastings it is known that a great thickness of them underlies the Weald.

Now, under Richmond the Cretaceous rocks are succeeded directly, as we go downwards, by the Middle Jurassic series; the whole Upper series is missing—we are in fact in presence of an unconformity. The material washed away from the top of the Jurassic system during its period of exposure went to make up the Bargate Beds, and indeed a great part of our Lower Cretaceous series.

The coast of Dorset, in fact, at the present day, repeats for us the shore of the Lower Cretaceous sea near London. Between Portland and St. Alban's Head we have many stretches of bay, in which pebbles and fossils from the Upper Jurassic sands and clays and limestones are being mingled with the shells of the period in which we live. We may picture such a coast lying to northward of the Weald, and slowly being encroached on by the sea. At one time the rounded limestone hills, with little river-gorges cut in them, sent down their waters into the Wealden lake; but in the days represented by the Hythe Beds the sea had encroached, and was already lapping round their feet. Cliffs were cut out, huge blocks of Jurassic limestone were broken up by the waves, and their fossil contents were scattered on the beach; and in most cases only fragments of the more resisting materials remained recognisable amid the rolling mass of pebbles. Down south, where Leith Hill was afterwards to rise, many

of these fragments, together with derived oolitic grains, became washed out into quieter waters; and here Cretaceous shell-banks stopped them and caused them to accumulate. It is pleasing thus to see how many details of the past can be brought before us by the study of a single cutting in the Bargate Beds, and by a careful sorting out of their constituents.

So the floor on which the marine Cretaceous strata here rested was unconformable to them, as must always be the case when we near a shore-line; and so far Jurassic strata were being used up again to make the Leith Hill sand-banks. Gradually the bays in this coast must have become filled with the broad stretches of the sand; for the **Folkestone Beds,** the next in upward order, are typically loose current-bedded materials, with all the character of sand-flats off a coast. Fossils are very scarce, owing to the porous nature of the beds, which has allowed the shells to be dissolved away by rain-water; and limonite cements the sand-grains along irregular water-ways, forming bands of dark brown "iron-stone," which stand out sharply upon weathering. Here strongly orange, here almost white, here a delicate warm brown or even pink, these sands form a beautiful feature of the lanes on the north fringe of the fir-woods. Then we emerge upon quite another country, the long hollow of the pools and streams.

Here is a fortunate little quarry, north of the Dorking and Guildford road, which shows us the actual junction of the Folkestone Beds with those above. The variegated sands, perforated by the nests of martins, pass somewhat abruptly into beds of stiff blue clay. Perhaps the denuding agents, working on the Jurassic rocks, began to wash down clays in place of sands; perhaps the sea-floor sank rapidly, and the finer materials alone could be deposited in this area. Certainly this clay, known as the **Gault,** is distinctly marine in character. When examined minutely, a good deal of sand and glauconite can be discovered in its lower portion; and it is well worth while to collect a specimen for the sake of the microscopic objects that it contains. If we dry fragments of the clay thoroughly on a dish in an oven, or on a metal plate over a Bunsen-burner, and then place them in a soup-plate full of water, they will break up with remarkable readiness into a very fine-grained mud. The finger must not be used to assist the disintegration of the lumps, as the particles

would thus become pressed together into clots; but a circular swaying motion must be given to the plate, by which the water becomes quickly thick and muddy. The water is then poured off gently, and more is added, the process being repeated until the lumps are entirely broken down and the greater part of their substance has been washed away. The residue contains any sand, glauconite, and shells that were concealed in the mass of the original clay. As usual, sifting will assist in dividing up these materials; the larger-shell fragments will remain in the 30-hole sieve (p. 105), and in 60-hole or 90-hole we shall find a number of exquisitely preserved foraminifera. Where these, however, are required in their most perfect condition, we must be content with thoroughly washing off the clay from them by swirling them about in a little water in the soup-plate, and then must select them by picking them out separately with a moistened and pointed piece of wood or a fine brush. In this way even the delicate knobs and spiny projections on the ornamented shells may be preserved.[1]

Nature works in much the same way in extracting the larger fossils for us from a clay. Let us climb up by the side of our quarry to the level ground above, where a little brick-yard has been opened in the Gault. Where the face of the cutting is fresh, the clay is stiff and sticky, and it is difficult to pick the fossils out of it without breaking them. But at the sides of the pit the rain has long been working on the sloping and exposed surface, and has washed down a good deal of the fine material into the form of flat and miniature alluvial fans. The coarse-grained residue higher up has dried and cracked in the sun, and readily breaks up under our fingers. The fossils can here be got out easily, and often retain a handsome pearly lustre. Little mineral change has gone on in the shells since the day on which they became embedded in the mud; the organic matter has decayed out of them, and they have become friable and flaky, while casts have been formed of their interiors by the clay which has hardened within them.

These fossils include numbers of the coiled cephalopod shells known as Ammonites, particularly the genus *Hoplites;* and a little brown spindle-shaped body, coming to a point at

[1] See F. Chapman, "The Foraminifera of the Gault of Folkestone," *Journ. Roy. Microscop. Soc.*, 1892, and succeeding years.

one end, can be found in almost any excavation. This is the "guard" of a small species of *Belemnites;* the animal was a cephalopod allied to the modern squids, but was furnished with a small straight chambered shell at its hinder end. This shell was protected by and sunk in a guard, popularly spoken of as the "belemnite," which projected backward and was built of close-set fibrous crystals of calcite. The modern cephalopods of this type manage to do without the guard, or possess the merest rudiments of it and of the ancient chambered shell.

The Ammonites that abound in the Gault are, like the Belemnites, entirely extinct; but the little bivalve *Nucula*, which also occurs in almost every Gault section, is still a living genus. All through the Cretaceous system, we shall find this mingling of extinct and living genera, such as we might expect near the top of the great Mesozoic group.

The Gault sea was of wide extent. We have no good evidence as to its boundaries on the north, but we know that it stretched right across the site of London and away towards Lincolnshire, passing into an iron-stained limestone in Norfolk. Up to the end of the deposition of the Folkestone Sands, a long-backed island or peninsula ran somewhat north-west and south-east across the London area. This old ridge has been struck again and again in well-borings, at about 1000 feet below the present surface. Now, beneath Kentish Town, and beneath Turnford on the north and Cross Ness on the east, the Gault clay, some 150 feet thick, rests directly on Triassic or Palæozoic rocks. Here we have, then, an unconformable junction of a most distinct character; at Turnford, indeed, we pass at once from the Gault to Devonian shales, which are uptilted at an angle of 25°.[1]

Beneath Kentish Town, however, a patch of Middle Jurassic limestone is left upon the ridge, which here consists of reddish sandstone, and the Gault follows immediately above this. Beneath Richmond similar beds occur, with 10 feet of nodular sandy limestones above, which are full of materials derived from the Jurassic rocks. Then follows the Gault, which is sandy and glauconitic at the base; so that at Richmond, in the specimens brought up by the boring-tools from depths of 1200 feet, we have written a

[1] See J. W. Judd, "On the Nature and Relations of the Jurassic Deposits which underlie London," *Quart. Journ. Geol. Soc.*, vol. xl, fig. 2, p. 760.

great part of the history of the Surrey Hills. We can picture, first, the Jurassic sea beating upon and finally overflowing the old sandstone coast, and depositing its wealth of sea-urchins and starfish and molluscan shells upon the sinking shore; secondly, we see the ridge upheaved again, and the Jurassic coating reduced by denudation to mere banks and patches of white limestone, while away to the south the Wealden lake and rivers spread out the products of its decay. Then, thirdly, the sea creeps north again, at first attacking the relics of the Jurassic rocks, and then protecting the remainder until our own time by the thick covering of Gault clay. It is by such observations, which seem slight in themselves, that we get an insight into what the older writers used to term the "revolutions of the globe."

A boring at Chatham[1] even gives us a glimpse of the geography of the Wealden lake. The Weald Clay occurs under the Atherfield beds twelve miles to the south, but is absent in the Chatham section, where the Cretaceous "greensands" rest directly upon Upper Jurassic clays. The border of the lake here was probably a muddy one, and lay somewhere in the limits of these twelve miles.

How far west did the sea of the Gault stage stretch? We have some answer to this in eastern Devonshire. As we travel from Taunton to Exeter, we see on our left the wooded promontories of the Blackdown Hills; and here, bared and brought to light, we have Cretaceous and Triassic strata in the same relations as those hidden away deep under London. The Gault beds have here overstepped (p. 219) the Upper, Middle, and Lower Jurassic series of Dorset, and rest upon the red Triassic clays. But they did not extend much farther west. We are already near the shore-line, for the fine Gault clays of Kent and Surrey are here represented by yellow glauconitic sands; these were deposited and churned up again by wave-action on a coast which remained in about the same position from the time of the marine invasion of the Weald to that of the Middle Chalk. The fossils of the Blackdown Hills are mingled in character;[2] but even the lowest Gault species are represented.

[1] W. Whitaker, "On some Borings in Kent," *Quart. Journ. Geol. Soc.*, vol. xlii, p. 30; and Jukes-Browne, "Historical Geology," p. 379.

[2] W. Downes, "The Zones of the Blackdown Beds," *Quart. Journ. Geol. Soc.*, vol. xxxviii, p. 92.

In our Surrey landscape, the ground rises steeply when we have crossed the flat of the Gault clay. The soil becomes at once drier and barer; the oaks and rushes and imperfectly drained marshes disappear; and we find ourselves at the foot of the long escarpment of the Chalk. The upper beds of the Gault are in many places composed of sandy limestone or calcareous sandstone, containing glauconite, and known as the "Upper Greensand"[1]; by its hardness, this rock often forms a little escarpment of its own, a local step that is a characteristic feature of the landscape (fig. 25).

Mr. Jukes-Browne has united the Upper Greensand with the more typical Gault beds under the name of "Selbornian." The sandy beds contain a number of siliceous sponges, mostly of a type known as lithistids,

FIG. 28.—*Ancyloceras gigas*, a cephalopod shell from the Aptian stage, Cretaceous period.

with somewhat knotty and irregular spicules. In the Selbornian strata generally, we find allies of the ammonites which have adopted strange fashions of coiling their chambered shells. The regular steady-going ammonites, which played so great a part in the molluscan life of the Jurassic period, are now represented by forms coiled in a screw-like spiral, or only loosely, so that successive coils are not in contact. These eccentric relatives also made themselves prominent somewhat earlier (fig. 28), and herald the complete extinction of the ammonites. Perfectly straight forms occur in the upper beds of

[1] See Jukes-Browne, *Mem. Geol. Surv.*, "Cretaceous Rocks of Britain," vol. i. (1900).

the Chalk; but, despite this variety of type, the great group of the ammonites did not outlive the Cretaceous period. *Nautilus*, which made its appearance in the Trias, with allies reaching far down into the Palæozoic era, has managed none the less to live on quietly to the present day.

We now reach the great mass known as the Chalk, often 1000 feet thick, which certainly merits sub-division into three stages, Upper, Middle, and Lower. Its fossils are well known, and their occurrence in zones has been carefully worked out. The researches of French geologists, and notably of Professor Barrois, first called attention to the interest of our English sections; and in the latest maps of the Wealden area, published by the Geological Survey, the Chalk is sub-divided according to the fossils it contains. The basement-beds were probably laid down at no great distance from a shore,[1] and are distinctly marly. This "Chalk Marl" constitutes the **Lower Chalk** stage. Sponges with more regular types of spicules are here frequent, and continue through the whole Chalk.

Complete solution of the skeleton has often occurred, and marcasite may have replaced it with its brassy substance, weathering to a rich orange-brown. Marcasite also forms nodules in the Chalk, which become rolled out into the talus-heaps of the cliffs or quarries. These nodules have arisen by slow aggregation of the iron sulphide into spherical or cylindrical lumps in the body of the consolidating chalk — a process of chemical rearrangement that is styled "concretionary action" (see also p. 221). The heavy nodules or concretions, brown on the outside, are picked up by country-people and are regarded as "thunderbolts," by which term meteorites are popularly designated. But no meteorite of this character has ever reached the earth, and the iron sulphide can often be shown to have accumulated round some fragment of a fossil or other solid body in the chalk. On being broken open, the marcasite shows

[1] Dr. Hume, however, considers that the Upper Greensand may have been formed at as great a depth as 150 fathoms ("The Genesis of the Chalk," *Proc. Geol. Assoc.*, vol. xiii. p. 222).

a fine brassy colour and lustre, with a radial structure, like that of spherulites and crystalline concretions in general.

The characters of the Lower Chalk division, which is so often marly, show that the Cretaceous sea was not yet deeper than 300 fathoms. The western shore still occurred somewhere away by Teignmouth and Exeter and Taunton, and the sea-floor was liable even to upward movements, whereby the Gault, which had already become consolidated, was broken up by waves and had its fossils scattered into the beds of later date. The decay of fish-bones and of materials rich in calcium phosphate gives rise at the present day to impure con-

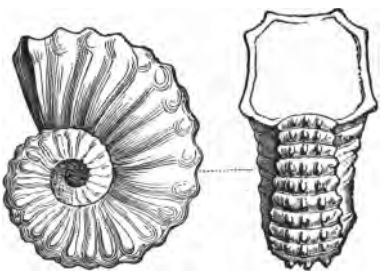


FIG. 29.—*Acanthoceras rothomagense*, an Ammonite from the Lower Chalk.

cretions of that material in marine deposits; shells become filled up by it, and lumps are formed irregularly about them. Similarly, many of the Gault fossils became "phosphatic," black casts of them alone remaining, often enveloped in black or dark-brown nodules. These bodies were washed out in places into the deposits of the Lower Chalk stage, and form a remarkable accumulation near Cambridge. Mr. Jukes-Browne states that they rest there on a worn surface of Gault, an evidence of the local unconformity. ("Cretaceous Rocks of Britain," vol. i. pp. 285–289.)

As we ascend our slope in Surrey to the quarries and the lime-kilns, and enter the white region of the **Middle Chalk**,

we may fairly ask what is the origin of the soft compact ground in which the larger fossils are here embedded. It has so uniform a character, it fills up the hollows of the fossils so completely, it becomes of such extreme whiteness and purity in the upper levels of the chalk, that it can scarcely result from the mere breaking up of previous limestones or of the shell-banks of the Cretaceous period. Something can be done towards its investigation by disintegrating the rock gently in water, aided by a tooth-brush; but the best way of observing its structure is by making a microscopic section. This is quite easy (see p. 25), if the soft rock is saturated with Canada balsam, which has been dried and rendered liquid again by heating. Then we see how the body of the chalk is composed of minute chambered shells, or of curving fragments broken from them. A fine mud of similar fragments, still smaller, and of the minute oval organic bodies known as *coccoliths*, fills up the chambers and cements the uninjured shells. Here and there a broken piece of a lamellibranch, or of the spine of a sea-urchin, occupies a great part of the field of the microscope. If we compare the finer material with the calcareous oozes now forming in our oceans, particularly in the Atlantic,[1] we shall have no hesitation in saying that the chalk is typically a foraminiferal deposit.

It cannot, however, be regarded as necessarily a deep-sea ooze. For a detailed discussion of the question of the depth of the Chalk sea, reference must be made to Dr. Hume's paper on the "Genesis of the Chalk,"[2] where the Upper Chalk is stated to have been deposited in the deepest water, the south-east counties of England remaining 500 fathoms under water from the end of the Lower Chalk age to the close of the Cretaceous period. Depths of 1000 to 2000 fathoms may have occurred; but it must be remembered that a broad shallow sea would fulfil most of the conditions. Distance from shore diminishes the abundance of many life-forms and the proportion of materials brought in suspension from the land, as distinctly as does increase of depth; and we shall see how the borders of the Cretaceous sea were steadily spreading northward and westward.

[1] See *Challenger Reports*, "Deep Sea Deposits," plate xi, fig. 1, and plates xii, xiii, and xiv.

[2] *Proc. Geol. Assoc.*, vol. xiii (1894), p. 211.

Professors Hébert and Barrois long ago called attention to the conglomeratic bands in the Chalk, which indicated, in their opinion, a disturbance of the sea-floor, its elevation so as to be within reach of wave-action, and the formation of succeeding beds from the rolled fragments of those immediately below. The occurrences that closed the Gault age in Cambridgeshire appear to be repeated several times in the Chalk, with remarkable uniformity over wide English areas. Thus there is a so-called "nodular" bed, the *Melbourn Rock*, between the Lower and Middle Chalk, the irregular and slightly worn lumps of previous beds standing out like nodules or concretions on the surface of the quarries; and microscopic sections will often show that there is a difference in texture between these derived fragments and the later chalk in which they are embedded.[1]

Dr. Hume[2] suggests that the alteration of currents by the submergence of old land-barriers, or the elevation of new

FIG. 30.—*Actinocamax plenus*, a Belemnite from the Middle Chalk; at the left end there is no cavity for containing the chambered shell.

ones, accounts for these conglomeratic bands. The associated fossils show no signs of shallow-water conditions, and Dr. Hume would regard the breaking up of the older beds as connected, in the case of the Melbourn Rock, with a steady depression rather than with elevation. A local unconformity in any case exists, and in South Dorset the conglomeratic condition occurs throughout the whole of the Middle Chalk.

The zone of the Melbourn Rock is not merely marked by its structure, which would be an unsafe guide in following it out across the country; but it is characterised by the occurrence of a curious belemnite, *Actinocamax plenus* (fig. 30), the massive guard of which did not include the chambered shell of the animal, but lay beyond its posterior end, still pro-

[1] J. W. Judd, "Jurassic Deposits which underlie London," *Quart. Journ. Geol. Soc.*, vol. xl, plate xxxiii, and p. 733.

[2] "The Genesis of the Chalk," *Proc. Geol. Assoc.*, vol. xiii, p. 229.

tecting it from injury in that direction. This prepares us for later forms in which the guard becomes shortened, and for those modern ones in which it has practically disappeared. Squids destitute of guards had, however, already made their appearance in the earliest Jurassic beds; but the protected ones flourished for a long time, and did not become extinct until the close of the Cretaceous period.

The Middle Chalk is a good white limestone, and sponges, and the little brachiopod *Terebratula*, and lamellibranchs, and sea-urchins, abound in it. Among the lamellibranchs, *Inoceramus* (fig. 31) is common, as it is also in the Upper stage; this genus often forms shells several centimetres across, which are corrugated with strong growth-lines on the outside and smooth and slightly waved on the inside. These broad flat shells have a very fibrous structure, the calcium carbonate forming little prisms perpendicular to their surfaces; and consequently they break up very readily, and all layers of the Chalk, especially in the Middle and Upper divisions, contain fragments of *Inoceramus*, which resemble little tiles or bricks. Their fibrous edges enable them, however, to be easily identified.

FIG. 31.—*Inoceramus Cuvieri*, from the Upper Chalk.

Flint or "chert" occurs often in the sandstones of the Selbornian stage, resembling the bands formed in the Hythe Beds. But it is absent in the succeeding strata, until we get well up into the Middle Chalk. Here we find characteristic lines of nodules, black when broken, and irregular in form, running along certain bedding-planes of the rock. A Chalk flint is typically white on the exterior, and is rather elongated in the direction of the stratification. It may be more than a metre long, but is commonly only about 20 cm. To determine the origin of these lumps of chalcedony, we must carefully examine the face of one of the great quarries. (See Plate VII.)

The flints obviously cannot be pebbles that became included in the chalk at the time of its consolidation. Their outlines are far too fantastic, and they have very often been formed round some white sea-urchin, or round a fragment of *Inoceramus* or other lamellibranch shell.

Some of the shells, moreover, have become filled with solid flint; so that we begin to see that this material has in some way been chemically deposited. Again and again, on breaking up a flint nodule, we find a hollow within, lined with white dusty projections; and in some fortunate cases the skeleton of a siliceous sponge falls out of this hollow, or remains in part cemented to its walls.

Here again we have the spicular origin of flint brought before us. The silica may have been extracted from the sea by sponges, may have been redissolved, and finally may have concreted round other sponges or round any convenient centre of deposition. Radiolarians and diatoms must not be forgotten as possible sources of origin for the silica.[1] It appears to be a principle that concretions will gather most favourably round material of the same chemical composition; as in the case of growing crystals, like is attracted towards like. We may expect, then, that the dissolved matter of the scattered siliceous remains throughout the chalk will accumulate again round undestroyed siliceous sponges. If these sponges form anywhere a fairly dense layer among the deposits, there a layer of nodular flints arises; but this does not seem sufficient to account for the abundance and regularity of the flint bands in ordinary chalk. It is probable that the dissolved silica went wandering in the waters which permeated the soft limestone for ages after its consolidation, and that it finally became deposited along those stratification-planes which were the easiest water-ways in the rock.

This is illustrated by the fact that layers of flint ("tabular flint") sometimes occur in the joints and planes of fracture of the chalk, and in all characters resemble the nodular flints, except in being more sheet-like and continuous. These tabular flints obviously must belong to a period far later than that of the consolidation of the chalk; and it is exceedingly improbable that the flints lying along the planes of stratification were formed at a much earlier date.

At any rate, we may safely conclude that the flints were never, as some have suggested, in a lumpy gelatinous condition on the floor of the Cretaceous sea. They came together molecule by molecule, not thrusting aside but

[1] See Hill and Jukes-Browne, *Quart. Journ. Geol. Soc.*, vol. li. (1895), p. 600.

actually *replacing*, the particles of calcareous mud, which had already accumulated to form fairly consolidated layers. The dull whiter patches that we see in so many flints are regions where the sponge-remains or shells still preserve some of their own individuality. In sections made across these patches, the outlines of foraminifera, of spicules, of shell-fragments—in fact, all the structure of true chalk—can be seen as if the mass were still calcareous. Some of the larger objects, such as pieces of *Inoceramus*, may remain unreplaced; but the smaller shells and the limestone-mud (coccoliths and broken foraminifera) have been converted into solid flint. The flint found in the sea-urchins or other shells has similarly replaced the fine chalk that originally filled them. Often additional flint has accumulated on the outside, while the shell has still remained calcareous. At last it may be dissolved away by comparatively modern percolating waters, and a perfect cast of the interior is left, loosely embedded in the outer mould.

These internal casts of the heart-shaped and ovoid sea-urchins are very common among the stones of the flint-gravels, which result from the decay of the Middle and Upper Chalk; and the frequent branching or simple hollows in many flint-pebbles in these gravels point to the material having accumulated round siliceous sponges.

The extremely fantastic surfaces of many unrolled flints is thus explained. The silicification of the limestone has spread unequally in various directions, and horn-like and knotty projections have resulted. In the old Carboniferous Limestone, precisely similar action is illustrated, and we can trace all stages between isolated nodules of flint and great uniform replacements of the rock over many metres of its thickness. In Jurassic and other limestones, oolitic structures have been replaced and exquisitely preserved in flint. It is quite clear, then, that the silica takes the place of the calcium carbonate during slow processes of change, and that in some limestones flints may still be growing. The decay of organic matter has possibly some chemical influence in promoting the deposition of the silica from solution, as it is believed to have had in the "wood opals" of various countries, in which all the delicate structures of tree-stems are wonderfully and microscopically replaced.

The outer layer of the flints from the chalk is singularly

white. The chalk itself may be washed off, and yet a dense white undecaying crust remains, which is seen in striking contrast to the black flint when we look at any broken specimen. Gradually, if exposed to weathering, the whole flint becomes dull and light-coloured; and this crust is believed to be due to the fact that the flint has ceased to grow and spread, and is being dissolved again by the permeating waters. It thus becomes minutely porous, the opaline particles of the chalcedony disappearing first; and we may compare the two parts of a common flint to obsidian and pumice, the one compact and almost transparent, the other white and opaque because of the multitude of internal reflections. Flints may decay away completely, if of small size, becoming as soft as chalk itself. I have thus written on a black-board with certain altered flints collected from a high and exposed gravel on Headley Heath; and in the field they might naturally be taken for chalk. But they do not effervesce with acids, and are practically composed of pure silica; the white crust has spread in this case through the whole mass of the flint pebble.

The boundary between Middle and Upper Chalk is marked by a second conglomeratic band, of which a stout ovoid sea-urchin, *Holaster planus*, is the characteristic fossil. Here we have, according to either theory of the origin of conglomeratic chalk, evidence of earth-movement, either resulting in elevation or in the readjustment of ocean-currents; and Dr. Hume quotes evidence to show that elevation actually occurred at this time in many areas, with a consequent increase in glauconite, and in materials, such as clay and small crystals, brought down by rivers from the land.

But the **Upper Chalk** itself, in its wide distribution, implies a farther extension of the great Cretaceous sea. It will take us too far away from our Surrey Hills to properly discuss this question; but already, from "Upper Greensand" times onward, the sea had spread west across our islands as far as the highlands of Derry and Donegal, and as far north as the area of Mull and Ardnamurchan. The Irish conglomerates of quartz pebbles, and the Scotch estuarine strata, show the presence of land along that north-west line; but the great sea, depositing pure organic limestone, now stretched eastward across the whole of Europe. The old ridge under south-east England was finally buried deep beneath 1000

feet of marine sediments, and there were no longer traces of even Jurassic hills in Surrey. Sea-urchins abounded, particularly the species *Echinocorys vulgaris*, with its flat oval base, *Echinoconus conicus*, a steeply conical form with the mouth central in its base, and *Micraster coranguinum*, a common heart-shaped form. These are among the very commonest fossils of the Upper Chalk; and at the top comes a belemnite, marked by a slit in the side of the hollow which protected the chambered shell, the species being entitled *Belemnitella mucronata*. This fossil is very common in the "White Limestone" of County Antrim, and occurs in Norfolk and the Isle of Wight. But in Surrey the high zone containing it has usually been denuded away, before the deposition of the clays and sands which form a capping to the Downs.

The Upper Chalk is rich in bands of nodular flints, while here and there a thin bed of yellow clay shows, as in the Middle Chalk, a temporary inflow of shore-material. In France and the northern parts of central Europe, a still higher chalk occurs, which may have been deposited in our area and then entirely lost by denudation. Certain it is that the tops of our Downs were greatly worn down before the opening of the Eocene period. Without more than a gentle folding, the floor of the Cretaceous sea became uplifted, and only sank again after hundreds of feet of chalk had been washed away. The flints became rolled into pebbles and fine sand, which went to build up the early Eocene beaches. Hence we must seek in France for a complete series of beds, marine throughout, to represent the great Cretaceous system. It is the old story of one set of geological observations leading on to comparison after comparison, until we want to travel round the globe to fill up all the gaps of knowledge. The names of the French stages, established by d'Orbigny and Desor, are now often used for the corresponding divisions in our own country.

The names of the stages given on page 279 are derived from districts where the beds are well displayed, their origin being, in descending order:—Denmark; the Senones, an old tribe near Sens, south-east of Paris; the Turones, a tribe near Tours; the Cenomani, a tribe near Le Mans, south-west of Paris; the Albis, the Roman name for the River Aube; Apt, east of Avignon; Barrême in the Basses Alps; and *νέα κώμη*, a fanciful Greek version of the name of Neuchâtel in western Switzer-

CRETACEOUS SYSTEM.

Series.	*Stages.*	*S.-E. England.*	*Ireland.*[1]	*Scotland.*[2]
Upper Cretaceous	**Danian**	Absent	Absent	Estuarine sands
	Senonian	Upper Chalk	White Limestone of Antrim, in part glauconitic and pebbly	Chalk
	Turonian	Middle Chalk	Glauconitic sand	Estuarine sands
	Cenomanian	Lower Chalk	Marls and glauconitic conglomerates and sands	Estuarine sands
Lower Cretaceous	**Albian**	Gault and part of Folkestone Beds[3]	Some beds of Upper Greensand type	Some beds of Upper Greensand type.
	Aptian	Part of Folkestone Beds. Hythe Beds	"	"
	Barrémian (or Urgonian)	Atherfield Clay	"	"
	Neocomian (marine)	Wealden Beds (fresh-water)	"	"

[1] See W. F. Hume, "Cretaceous Strata of Co. Antrim," *Quart. Journ. Geol. Soc.*, vol. liii. (1897), p. 598.

[2] See Professor Judd, "The Secondary Rocks of Scotland," *ibid.*, vol. xxxiv, p. 728, &c.

[3] See J. W. Gregory, "Fossils from Great Chart in Kent," *Geol. Mag.*, 1895, p. 103.

land. The name Neocomian was formerly used for the whole of the stages up to the base of the Albian. The line between the Upper and Lower Cretaceous series is usually drawn in England at the base of the Albian; but the alliance between the Folkestone and the Hythe beds, and the suggestion of unconformity between the Gault and the Cenomanian, seem to make the Continental custom preferable, as indicated above.

By the removal of much of the British Cretaceous strata, the marine Eocene beds, when the land again sank, overstepped (p. 218) various stages of the Chalk, and are found resting in places on Middle Chalk on the edges of the Surrey Downs. We learn, from following out this unconformity, that the North Downs, as hills, have had at least a double history, and that the dome across the Weald began to be denuded at the close of the Cretaceous period. Then it sank, to be covered by the pebble-beaches and clays which extend away to London.

We must now finish our climb up the barren face of the Downs, and enter the beech-woods on the summit. Here we shall again and again come across patches of beautifully rounded flint pebbles, sometimes pure black in a matrix of rich brown loam, sometimes altered and bleached to a pale yellow in the midst of permeable sand. These are traces of the shore-deposits that heralded the new incursion of the sea. The distribution of the Eocene beds shows us that a great part of Britain remained above water, gulfs alone being now formed in the area lately occupied by the broad Cretaceous sea. The escarpment of the London Eocenes forms another ridge facing us as we walk down the dip-slope of the Chalk; it draws near to Guildford on the west, and we cross it at Leatherhead, after which, as we return to London, it forms a number of clayey and hilly commons on our left.

The flat-topped hills that stand out in the north-west (p. 245), such as St. George's Hill near Esher, are formed of the level Upper Eocene sands. Hence, like the Leith Hill country, they are given over to dense fir-woods, which form a region of singular gloom from Bagshot Heath to Aldershot. The yellow roads run through forests, in which every interval between the pink bare stems is occupied by farther and farther trees; no light reaches the highway, except from immediately above; and only here and there, in some sudden clearing, we can realise our height above the surrounding

country, and see the sunlight gleaming on the open Downs to southward.

The unconformity between the Eocene and the Cretaceous is not to be observed in any single quarry, the one set of beds lying fairly evenly on the other, and both having been subjected to the same earth-movements in recent times. But the solvent action of percolating water has produced striking appearances of local unconformity. In the great chalk-pits, we must have noticed how the upper layers were frequently traversed by wedge-like masses of brown sand, coming down vertically from the surface of the Downs. These are what the quarrymen call "pipes," and are regions where solution of the chalk has allowed the Cainozoic beds to fall in. The pipes are probably still being elongated at the present day, and the surface-soil above them becomes correspondingly depressed. Often on the back of the Chalk, particularly towards sunset, the light picks out circular hollows in the broad curvings of the fields; in some cases these are so deep that the plough can no longer be driven into them, and they have to be abandoned to a growth of bushes, which they shelter and protect. These depressions are known as "swallow-holes," and represent the upper ends of "pipes," their growth and spread being due to the underground solution of the chalk.

The plane of junction between the Mesozoic and Cainozoic strata thus becomes very irregular. Sometimes a huge pipe comes down obliquely into the section formed by the quarry-face, and then appears as an oval mass of sand and iron-stained flints, in the midst of the pure white chalk. The workmen, requiring only the limestone, excavate round this mass, and finally it is left standing out as a brown buttress, its connexion with the surface being now revealed.

We must not push our investigations farther towards London, except to note that the Eocene sea ended in an estuarine period, and that finally, in Miocene times, the British Isles generally became dry land. But the North Downs went under water again at the opening of the Pliocene period, since some of the pipes above Lenham in Kent contain marine fossils of that system. A number of casts, in sandstone richly stained with limonite, are found included in the material which has been lowered into the Chalk; these useless lumps of "ironstone" are thrown aside by the

quarrymen, and are well worth breaking up with the hammer. One may thus find casts of *Terebratula grandis*, and other unmistakable Lower Pliocene fossils, such as were relied on by Mr. Clement Reid in proving the age of these interesting relics.[1]

Hence the Surrey Hills, in their present form, are very recent in their origin. If the sandy beaches of a Pliocene sea were spread over the denuded Eocenes, just as the latter had previously been laid down across the Chalk, we must recognise that the area, as we now know it, has undergone a third upheaval, practically in Post-Pliocene times. The Lenham pipes are now 600 feet above the sea, and traces of them are found at various levels on the face of the escarpment, showing that the chalk ridge has been worn back since they were deposited and since they were lowered by solution into it. Hence man himself probably existed on the earth before the Surrey Downs were made, and before the Chalk was so far cut away as to expose even the Aptian rocks beneath it. If we give one last look upon the landscape that spreads around us from Leith Hill, the extremely modern character of the present features becomes impressively brought home to us. All the rich variety of scarp and hollow, all this freshest beauty of south-eastern England, seems but a trifling incident compared to the great changes of the past. And we may picture this land of ours, in the next swing of the continental edge, sinking once more beneath the waves, and the delicately fashioned scenery of our own time vanishing like that which once lay around the Wealden lake. But, after all, our stage is not yet run out; and our successors, if they lose the Surrey Hills, may be rewarded by the possession of still newer landscapes, and of still keener perceptions to enjoy them.

If domes of strata rise out of the sea, and are carved into escarpments and long hollows, so also our greatest mountains have originated in foldings of the crust. There are surprises still in store for us if we again journey into Switzerland; and on this occasion we will do things gently, like old-time travellers, and leave the train at Dôle, well between the Côte d'Or and the Juras. Thence we will cross the hills by road, and so, from the Surrey Downs, attack the passes of the Alps.

[1] Reid, "The Pliocene Deposits of North-Western Europe," *Nature*, vol. xxxiv (1886), p. 341.

CHAPTER X

THE FOLDS OF THE MOUNTAINS

In the Weald we have seen how the denudation of a great fold has produced a considerable variety of surface, though the repetition of the features is clear on opposite sides of the anticlinal. But a series of anticlinals and synclinals, a series of approximately parallel earth-wrinkles, can bring scarp and hollow in rapid succession into the landscape; and, if the slopes of the anticlinals are at various angles, the contrasts between one ridge and another may become sharply marked. In general, the term **folded strata** has come to mean strata bent into a series of such wrinkles; and, where the folding is extreme, we speak of it as **contortion** (Plate XI).

In ordinary folded strata, denudation may remove the tops of the folds, while their bases may be hidden underground. The anticlinals and synclinals may be nipped by pressure in their central parts, and may expand above and below the region of greatest compression. Where such an anticlinal expands, the beds of its two halves or "limbs" slope outward and upward away from one another, and denudation may expose only this upper portion. The older beds are still in the centre of the fold, but the effect on the eye is that of a synclinal. Such an arrangement of the strata is frequent in the heart of mountain-areas, and is appropriately known as **fan-structure** (fig. 32), from the appearance, on the bare rock-walls, of strata radiating like the bars of an opened fan.

In contorted beds, the folds may become pressed over in one direction, so that their two limbs are parallel over long distances. In the sections exposed near the surface of the earth, it may be difficult to discover the anticlinals and synclinals, and the whole series looks like one limb of a huge denuded fold. But careful search will often reveal the repetition of some characteristic bed, such as a shell-band or a coal-seam, by which the true arrangement can be worked out (fig. 33).

Where one side of an anticlinal or a synclinal comes thus to lie upon the other, we may call the whole a

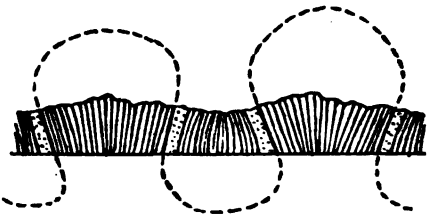


FIG. 32.—SECTION ILLUSTRATING FAN-STRUCTURE IN A MOUNTAIN-CHAIN.

The dotted lines show the original anticlinals and synclinals, now worn down by denudation.

recumbent fold; and it is clear that in the under limb of such an anticlinal the beds follow one another in a

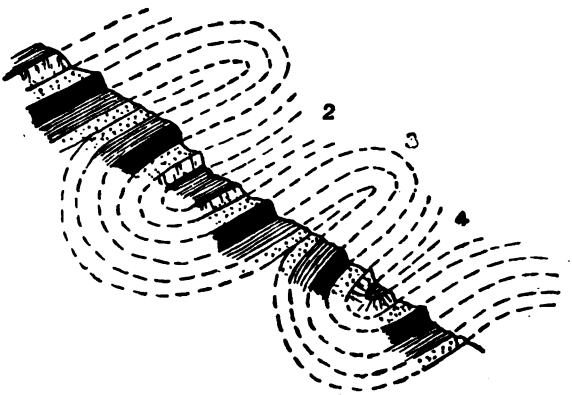


FIG 33.—SECTION ILLUSTRATING REPETITION OF STRATA PRODUCED BY RECUMBENT FOLDS, AS SEEN IN ASCENDING A MOUNTAIN-SIDE.

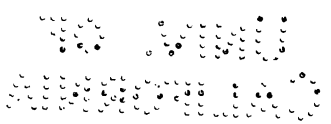
In the anticlinals 1 and 3 the strata are reversed in the lower limbs of the folds; in the synclinals 2 and 4 the reversal is in the upper limbs. Such folding is usually complicated in nature by thrust-planes.

reversed order, the older ones resting upon the younger. In the case of a recumbent synclinal, the reversal

CONTORTED UPPER JURASSIC STRATA, STARE COVE, LULWORTH, DORSETSHIRE.

A recumbent synclinal occurs in the left-hand upper portion of the cliff.

PLATE XI.] [*Photographed by* Mr. J. J. COLE, F.R.A.S.



takes place in the upper flank of the fold. (See figs. 33 and 37.)

These are only some of the difficulties that geologists encounter in dealing with strata which have been subjected to considerable earth-movements. The whole mass often gives way along a certain plane of fracture, frequently by the rupture of a fold, and the beds on one side of the plane slip up, while those on the other side slip down, the effect being what is called a **fault** (fig. 34). The amount of shifting away of a bed from its normal position, due to faulting, may vary from two inches or so to perhaps two miles. The connexion between faults and folds is often seen by the strata being bent up towards the plane of frac-

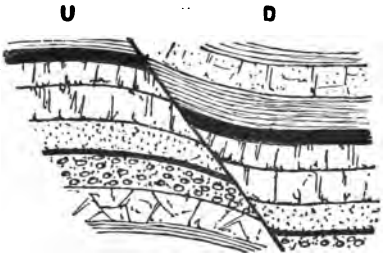


FIG. 34.—SECTION ACROSS A FAULT, showing the strata bent down on U, the upthrow-side, and upwards on D, the downthrow-side.

ture on the side that has been lowered, or on the *downthrow* side, and down towards it on the opposite, or *upthrow* side.

A fault, as we may see it in horizontal beds in a Surrey chalk-pit, or in one of the red clay-pits of the Midlands, presents no especial difficulties; but faults, when we cannot see them in section, may puzzle us by producing a repetition of the beds upon the surface. A fault along the strike of uptilted beds causes a part of the series to begin over again, with a corresponding repetition of the scenery to which it gives rise; and a fault more or less parallel to the dip carries the inclined beds forward on the side that has been dropped, so that their outcrops end off abruptly against the fault-plane, and their continuation has to be sought for at

some distance away along that plane (fig. 35). In looking at a geological map, this *lateral shift* can often be observed (the faults in English maps are represented by white lines); and the downthrow side, or that on which the beds lie at the lower level, can be determined by the following rule:—

In tilted strata, all faults, except those parallel with the strike, cause a lateral shifting of the outcrops, and thus older and younger strata are brought into contact at the fault-plane; the side on which the younger stratum of any pair lies is that on which the beds lie at the lower level. That is, therefore, the *downthrow* side of the fault.

In most faults, the plane of the fault slopes down towards the downthrow side, as in fig. 34; when it slopes towards the upthrow side, we have a **reversed fault**, and the beds on the downthrow side come to lie below their representatives on the upthrow side. Where we have a reversed fault with the fault-plane nearly horizontal, it is called a **thrust-plane**; masses of strata may be moved along it for several miles, and may be left stranded on the top of materials of an utterly incongruous character. A perfect puzzle may result; the tops of anticlinals may be brought directly over the bases of synclinals, an oval grouping of strata being the result, while horizontal beds are often caused to lie upon vertical ones, with an appearance of striking unconformity. Yet in this latter case the two discordant series may be in reality one and the same, the horizontal top of some broad anticlinal having been carried forward on the thrust-plane until it rests above the vertical beds of one of its own limbs.

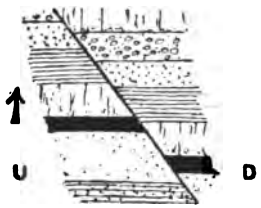


FIG. 35.—PLAN OF A FAULT IN INCLINED STRATA, AS SEEN UPON A GEOLOGICAL MAP.

The arrow points to the spot towards which the beds dip. D and U as in fig. 30.

One puzzling effect of gently sloping thrust-planes is to bring up strata from the depths and to land them on those that are much younger. To see what the field-surveyor has to face, it is well to draw imaginary contortions with chalk upon a piece of brown paper; then cut the whole across along an approximately horizontal line, and shift the one

half over the other, noting the great variety of apparent unconformities produced, according to the extent of the movement. An ecstasy of confusion can be reached by drawing a contorted series in which true unconformities and ordinary faults already exist, and then dividing that by a great thrust-plane. One may imagine the joy with which well-marked fossil zones are hailed in a country where the structural features have obliterated in this way all the original relations of the strata.

Thrust-planes very often occur through the heart of a recumbent fold, the opposite limbs of the fold becoming drawn far away from one another along the plane of fracture.

In all varieties of faulting, we have no evidence of rapid action in the tearing and displacement of the beds, but rather of long slowly acting pressures, which at last could not be resisted, the rocks yielding gradually, and shifting their places year by year. A number of sudden little slips, however, probably occur during such movement, a shock being given at each slip to the beds on either side. Some one has hence aptly described faults as "fossil earthquakes."

Often a broken and mingled mass of rock occurs along the plane of fracture, its angular fragments being derived from all the rocks affected by the movement. This broken material is the **fault-rock** or **fault-breccia.**[1] We must remember that most rocks in a contorted series cannot break up, since their parts are under such pressures, exerted all round them, that they have no room in which to slide apart. But sometimes there are masses of a compressible or yielding character lying between harder and more resisting ones; then the former series begins to be deformed, and to flow in a direction perpendicular to that in which the main pressure is exerted; and this allows the harder but more brittle masses to break up, so that they are pressed in fragments into their softer neighbours. A breccia results, of all degrees of coarseness; and we have often to trace it to some distance before we can determine its true character. Thus, on the promontory of Howth near Dublin, hard quartz rocks have been crushed and broken among the shales, with which they once formed a conformably bedded series. When an

[1] Pronounced *bretshia*, the word being Italian, and having been originally applied to a number of ornamental stones composed of angular fragments set in a natural cement.

igneous mass thus becomes "brecciated" under earth-movements, it may easily be mistaken for a volcanic tuff.

The flow of yielding beds to escape from pressure is illustrated in many common outcrops of tilted strata. An immense number of small cracks are seen in the beds, running perpendicular to the strike, and perhaps rendered conspicuous by an infilling of quartz or calcite. These cracks result from the oozing away of the beds under the pressure which has produced their tilting.

Armed with these ideas, we may now set out upon our next and longest journey. We have crossed the Paris Basin, which is so like the broad synclinal area of London, with the Cretaceous beds fringing it, their escarpments facing outwards in a ring; we have climbed to the very sources of the northern rivers, and have seen the Seine and the Marne diminishing on the great Jurassic plateau; and now we are down from the Côte d'Or, across that escarpment also, and ready to attack the folds of the long blue Juras and the Alps.

The great ridge behind us, worn out of the Middle Jurassic limestones, forms one flank of a valley fifty miles wide, the other flank being found in the Jura range about Poligny. The Saône, descending from the Vosges, and its tributary the Doubs, almost parallel to it, here unite to form a river worthy of such a valley. Beneath and beyond their modern alluvial reaches, the whole wide hollow is covered with a plain of Pliocene gravels, which choked the original valley soon after it was excavated. *Paludina*, the common freshwater gastropod, occurs in some of the associated marls, and the bones of extinct elephants, *Elephas meridionalis* and *antiquus*, indicate the age of the deposit. The valley, then, is somewhat older than our Wealden excavation, and was filled with gravel from the Jurassic slopes round it in Upper Pliocene times.

From Dijon, at the foot of the Côte d'Or escarpment, to Auxonne, the ground is practically level; but just before the quaint old town of Dôle we come over the shoulder of a gentle hill. To the north there rises a broad-backed ridge, some ten miles long, which forms a barrier between the Rivers Saône and Doubs. The rocks composing it are folded masses of Triassic and Permian strata, resting on granites and "gneisses," which are at least older than the Carboniferous period. This little

ridge of Dôle is a model, as it were, of the great forest-range of the Vosges farther to the north, and is by far the most interesting object in the valley. On its flanks Jurassic rocks were deposited, which form the hilly ground on which Dôle itself is built; but the great stretch of Pliocene gravels has hidden almost all these older features. The Dôle ridge is in reality a projecting part of a buried continuation of the Vosges; it is a survivor of a mountain-range older than Jurassic times, and in part older than the Carboniferous period; and it speaks to us of a European continent which passed away almost completely beneath the Jurassic sea. Doubtless, between Dôle and the central plateau of Auvergne (p. 148), other peaks approach the present surface; and we shall soon see how these buried mountains have asserted themselves in resisting more recent earth-movements.

After the steep streets of Dôle, we have another fifteen miles of extremely level country, across the old gravels and the later alluvium of the Doubs; but a few rolls of hills soon begin to rise up against us, and at Mouchard we pass under a railway-arch and are suddenly in a new world. The railway runs south, avoiding the mountains, which here rise quickly from the plain. The unconformity between the gravels and the Juras is as marked as that between the great plains of India and the Himálayas, and the change of scenery is equally abrupt. We are now among the masses which have showered down all these limestone pebbles into the valley. The road begins to climb in windings to the head of a long combe; the streams flow down swiftly under fir-woods and great limestone scars; and the side-valleys are flanked by bold cliffs and craggy promontories, on which the fortresses of the frontier are set proudly, tier on tier. If Auxonne is a typical city of the plain, Salins, on the other hand, massed upon a cliff-set slope, is typical as a mountain-stronghold. Mile by mile we push up into the forest, meeting cows with bells about their necks, driven by peasant-girls, and enormous timber descending on carts drawn by oxen, and all the life of a highland roadway under the clear cool mountain-air. We are now well up among the Juras, which stretch to the north-east beyond Bâle, and on the south to Chambéry, a range of 200 miles.

Travellers by rail into Switzerland also know well this sudden transition from the gentle lowlands to the Juras.

Even on the route to Bâle, where we climb somewhat mildly at the first, we wake up after the long night-journey, to see the clouds wandering among crags and pinnacles, and the rivers foaming in limestone cañons far below. The long escarpments are here far bolder things than in our homely and simple Surrey hills. The dip-slopes are often as steep as the scarped fronts, and the frequent folds cause them to face now this way, now that, in the complexities of the same mountain-landscape. The valleys are cut deeply into the pale grey rock, which often rises in characteristic vertical walls, like those of the Cheddar gorge in Somerset; and these irregular cañons form the defiles known locally as *cluses*. Occasionally some wider valley-floor thrusts back the fir-woods on either hand, and its soil is given over to cultivation. The villages, which die away in the *cluses*, are here grouped close to one another along the road, six or seven being in view at once. Clearly some attraction beside the Jura limestone has drawn these agriculturists together.

After the broad grassy uplands of Pontarlier, where we are on the real crest of the mountains, with the ridges only feebly emerging round us, we enter another defile and cross the frontier into Switzerland. The descent of the Jura is far severer than the western ascent; but the steep valleys are broken here and there by some oval alluvial area, the floor of an old mountain-lake. The busy little towns, alive with mechanical industries, take advantage of these level patches; and in between them the road may have to be cut in the side of sheer limestone cliffs, to secure a passage from one town to another. Far below, we may see the old mule-track, struggling with the torrent for a place in the floor of the ravine. As we come down on Neuchâtel, another huge valley, like that of the Saône, opens before us, with blue lakes lying in it. One flank is formed by the Jura mountains, but the other is still more magnificent; for we see there, twenty miles away, the blue-grey foot-hills of the Alps, with the snow-masses of the central range, thrice as distant, towering, like sunlit clouds, beyond. This first glimpse of the Alps is one of the most impressive features of our journey. While we are pausing among the cliffs and forests of the Juras, we know that their mightier rivals wait for us across the lowland. When we finally approach them, we shall be lost in the complexities and indentations of their denuded sur-

face; but here, as at Schaffhausen and other distant viewpoints, we can grasp all their grandeur as a massive and continuous mountain-range.

The Juras are built almost entirely of Jurassic strata, consisting mainly of massive and pale grey limestones; and their folds have considerable regularity, striking north and south from Chambéry to Geneva, and then gradually curving round, until at Bâle they strike E.N.E. It very often happens in denuded areas that ridges are carved out of the heart of synclinals, because the beds in them have become pressed together and made more resisting; while the anticlinals, on the other hand, give way along their crests, producing valleys running parallel to the strike. But in the

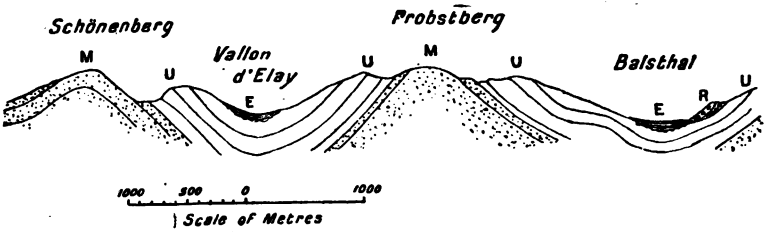


FIG. 36.—RIDGES AND VALLEYS FORMED BY FOLDS IN THE JURA MOUNTAINS.

E, Eocene lacustrine deposits; M, Middle Jurassic; R, recent deposits; U, Upper Jurassic. (After Rollier, "Livret-guide géologique," pl. iii.)

more gently folded regions of the Jura, where faults and reversals of strata have not complicated matters, there are long ridges formed by anticlinals, and valleys lying in synclinal hollows; so that the general structure of the range has always been referred to as one of unusually simple and diagrammatic character (fig. 36). Faults and reversals, however, occur, approaching those of the Alps themselves in disguising the true relations of the strata;[1] and the total chain now occupies only two-thirds of the space that its strata covered before the folding-processes came into play.

Cretaceous beds are found in the Juras; but, with a few exceptions on the west, only the lower series appears to

[1] See Bertrand, *Bull. Soc. géol. de France*, 3me. sér., tome x, p. 119

have been deposited; hence we conclude that an upheaval occurred along this line about the middle of the Cretaceous period. But the valleys along which so many of the villages cluster are floored with fresh-water Eocene and estuarine Oligocene beds, oysters occurring in the latter. The sea was not completely thrust out of the area in Lower Oligocene times; and north-west of Solothurn we find traces of marine incursions even among Miocene strata.[1] The Miocene of the Juras is in general fresh-water; but the deposits are folded, and are preserved along the synclinals of Jurassic rocks. Hence the great and final squeezing of the Juras to form a mountain-range occurred as recently as the end of the Miocene period. Prior to that, a promontory rose here, bordered by scattered islets; and in early Cretaceous times scarcely a rock had appeared above the sea.

The form of the range as a whole must have a meaning; and here our minds go back to Dôle, with the little boss of ancient crystalline rocks appearing above the surface of the plain. If we carry on the line of this ridge to meet the Vosges, we see that the old axis of the Vosges-Dôle mountains ran parallel to that part of the Juras which lies to the south-east. Beyond Bâle, the similarly old granite mass of the Black Forest forms another landmark of the ancient floor of Europe; and it is just against this region that the Juras begin to swing round to the east. Turning to the other end of the chain, we see that west of it, across the alluvium of the Saône, the central core of France sends out long ridges to the north, parallel to the adjacent Juras. It now seems certain that the earth-movements which compressed the chain exerted pressure from the south-east; the upper layers of the crust became wrinkled up, but the far older mountains of Europe acted as buttresses to resist the movement. Forced against the hidden slopes of the central plateau of France, against the ridge of Dôle, extending to the Vosges, and against the stubborn highland of the Black Forest, the whole chain assumed a crescentic form, its concave side being towards the direction from which the pressure came. We thus gain a fine conception of the sliding of the Mesozoic beds over a land-surface which had long been buried, and on which they had been unconformably laid down; and

[1] "Livret-guide dans le Jura et les Alpes," *Congrès géol. international*, 1894, p. 23.

we see that, because the ancient ranges had run from the south to the north-east and east, our far later Juras were forced to take up the same curve.

We must now pass out from Neuchâtel, with its cuttings in the yellow Neocomians, and ascend the valley of the Aare. We cross a somewhat irregular lowland, cumbered with materials brought down by rivers and glaciers in recent times, and rise from Berne into the true foot-hills of the Alps. Round us are wooded knolls, as large as British mountains, formed of upturned Miocene and Oligocene strata; some of the Miocene beds are marine, and yet they are clearly involved in the movements that have made the Alps.

Huge banks of conglomerate occur in the Miocenes as we near the central range. The bedding is sometimes shown by the arrangement of the pebbles, and we see these old delta-cones and alluvial flood-banks now pressed together and folded, and sometimes absolutely set on end. The blue clays of the Miocene sea, with a wealth of molluscan shells, are abruptly overlain in places by these thick conglomerates. A fine study may be made of them away in the north-east, close above the town of St. Gallen. Here the earth-movements have crushed the pebbles into one another, the limestone pebbles becoming dissolved under the stress, and receiving perfect impressions from those forced into their surfaces. Everything speaks of the greatest earth-movement and pressure; and yet these beds were contorted as recently as the Pliocene period.

But a mountain-range must have existed near at hand to supply the abundant pebbles. Near Thun, as we reach the first lake on the Aare, we find pebbles of limestone, worn from the Cretaceous and Jurassic rocks, forming whole banks of the conglomerate. With them are pebbles of granite and other crystalline rocks, such as we shall study in the central ridges; so that these older masses had in part become uncovered and denuded in Miocene times. The conglomerates, indeed, represent a period when something like the Alps existed to the south, but when the Mesozoic limestones occupied a much larger area on the surface than they do at present.

Farther on, as the road is cut and tunneled in pale yellow limestone above the Lake of Thun, we find fossiliferous beds full of large foraminifera, the genera *Nummulites* and *Orbitoides*

being predominant. These are Eocene marine beds, the so-called "Nummulitic strata" of the Alps. They have a strangely massive and compacted air when compared with our gently dipping clays and sands of the same age in south-eastern England (p. 280).

Ribs and ridges of Cretaceous and Jurassic limestones, grey and pale as in the Juras, now appear from under the folded Eocene; and at Interlaken, between the Lakes of Thun and Brienz, we have left the Cainozoic foot-hills, and find the Mesozoic rocks, crushed and bent and reversed in order, against the huge wall of the Bernese Oberland.

We are now in the country of the lakes, with that of Lucerne temptingly in the north-east, and the great Lake of Geneva in the south-west. Following the strike of the strata in the foot-hills, we cross the Brunig Pass, which is merely a notch caused by the cutting back of the head of a northern river into the wall of the valley of the Aare. As we descend towards the Lake of Lucerne, we have Eocene and Oligocene masses piled 4000 feet above us on the left, and Eocene and Jurassic beds alike infolded towards the summit of the Titlis, 10,000 feet above the sea upon our right. The later earth-movements, then, have clearly resulted in serious mountain-building.

The lakes themselves may claim our attention for a time. What connexion have they with the general structure of the foot-hills? The Lake of Thun may have accumulated behind the great alluvial banks which choke the valley from Thun to Bern; and the flat between this lake and that of Brienz is clearly formed by the encroachment of a delta due to torrents coming from the south. But the depth of the floor of these lakes would probably suggest additional causes of their formation. When we reach the Lake of Lucerne, with its singular winding form and its long inlets, we are irresistibly reminded of our west-coast fjords. The valley that we descend from Sarnen is continued by one of these inlets; to the west, the Reuss issues along another; and the lake stretching up to Kussnacht seems to have occupied the whole of a valley-floor. A rise of 80 feet in the waters of the lake would extend it up another valley from Brunnen towards Schwyz, and would connect it across the low *col* with the Lakes of Lowerz and Zug.

The grandest portion of the Lake of Lucerne is from

Brunnen south towards Altdorf, where the walls come down almost vertically into the water, while the railway finds room only by tunneling, and the road climbs high above, cut into the face of the cliff. It is a repetition of the steep features of the north shore of the Lake of Thun. Surely here we have a flooded valley, with a plain of alluvium forming beneath the water in its floor (compare pp. 81 and 141).

The depth of the lake in places reaches 850 feet, that of the Lake of Zug being 1320 feet; in neither case can a vast alluvial dam be pointed to as the cause of this great accumulation of the waters. The Reuss runs out at Lucerne through a narrow groove cut in Miocene hills; but no river can have excavated the deep and narrow bed of the lake, as we now know it, between Lucerne and Altdorf. Yet the whole plan of the lake is clearly connected with the rivers; the explanation must be that the Alpine movements continued even after the Reuss had carved its channel, and that the floor of the valley became bent, either by an uptilt near Lucerne, or by a subsidence of its central and upper portions. Considering the length of the lake, some twenty-four miles, a small angle of earth-movement would suffice to give it considerable depth.

It is now believed that the Swiss lakes as a whole result from the formation of local depressions, and partly from a sinking of the central Alpine chain,[1] which here and there has actually reversed the direction of the slope of valley-floors in certain regions. The great Lake of Geneva, which is similarly a feature of the foot-hills, is thirty-seven miles long, and 1014 feet (309 metres) deep. The detrital cone of the Rhone goes down steeply under the water, much like an alluvial cone on a mountain-side; but the steady flow of the river washes out the finest material, and spreads it with remarkable evenness over the central floor.[2] The original hollow formed by earth-movement was evidently much deeper, and is being filled up by an extraordinarily uniform and level alluvial flat.

The formation of lake-basins through the occurrence of movement in the floors of valleys has gone on equally on the broad surfaces of continents, as in the case of the inland

[1] Forel, "Le Léman," tome i, p. 231; *Heim*, "Die Entstehung der alpinen Randseen," *Vierteljahrschr. naturforsch. Gesell. Zürich*, Bd. xxxix (1894), p. 81.
[2] Forel, "Le Léman," tome i, p. 51.

seas of North America, and among the narrow grooves of mountains, as in our Scottish highlands. Loch Ness is thus a flooded portion of the Great Glen, 20 miles long, 1½ miles wide, and 774 feet in depth.

Hence the lake-region brings the period of folding in the Alps very near to our own time; and occasional earthquakes, particularly at the Venetian and Croatian end of the chain, point to the actual continuance of movement, upward or downward, at the present day. These mountains, then, which began their great uplift through the waters of the Eocene sea, are not even now in a state of equilibrium and rest.

The upper half of the Lake of Lucerne lies among the folds of Cretaceous strata, which are superbly seen upon the mountain-walls that bound it. The Upper Cretaceous series is here present, showing that the Alps did not share in the early upward movement which made the Juras a promontory in the Cretaceous sea. The Miocene conglomerates have been carried up and contorted to form the summit of the Rigi, 5906 feet above the sea; and in the valley at Altdorf the nummulitic Eocenes have become bent in under the Lower Cretaceous beds, a fine example of reversal. As we commence the ascent of the St. Gotthard Pass, these marine Eocenes lie caught in above us on the peaks of the Windgälle (fig. 37), forming a long recumbent synclinal; Jurassic strata wrap round them, and tower in crags above them in the reversed upper limb of the fold. This is the last we shall see of the Cainozoic beds on this side; for we are now on the threshold of the crystalline masses which compose the central Alps.

The contrast between these and the Jurassic and Triassic beds, which are thrust across their upturned edges, is at first of the most unmistakable character; but we must be on the look-out for synclinals of the Mesozoic rocks folded deeply into the heart of the chain. The junction is no longer merely an unconformable one, but is complicated by the fact that the Mesozoic sediments and the underlying crystalline rocks have all been involved together in the greatest earth-movements of the Alps. The eroded coast of Mesozoic times, the sands and muds and limestones formed against it, and the sea-floor on which they lay, have all been rolled up as if they were a mere film upon the surface of the earth. It is as if we were to lay down two or three thicknesses of

carpet to cover up the irregularities in the floor of some old cathedral, while changes in its level still go on. At one point the supporting arches of the crypt give way, at another the columns remain firm; and finally the floor becomes bent and broken, the carpets, and the layers of dust upon them, rising and falling on its folds. The crypt thus represents the unknown masses of the inner crust; the floor is the

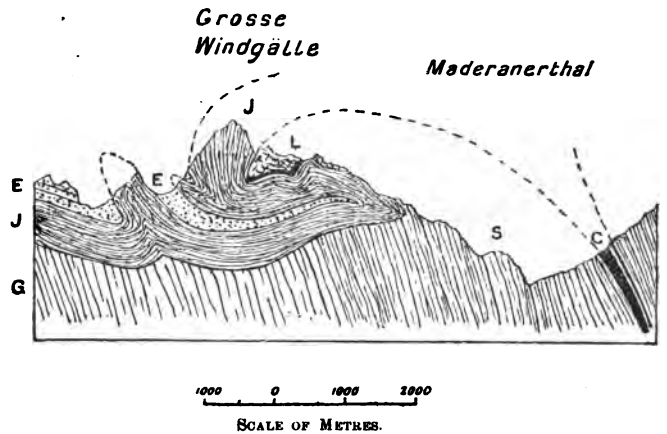


FIG. 37. – RECUMBENT SYNCLINAL AND FOLDING ON THE WINDGÄLLE, IN EASTERN SWITZERLAND.

C, Carboniferous, repeated also under the letter L; E, Eocene; G, Gneiss; J, Jurassic; L, Lavas of Carboniferous age; S, Schists. (After Heim and Schmidt, "Livret-guide géologique," pl. viii.)

ancient crystalline ground of Europe; the carpets will serve for the Mesozoic sediments, and the dust upon the topmost one for the Eocene and later accumulations.[1]

The rocks that we now meet with in climbing the central range have mostly a distinct structure, formed by alternating layers of different crystalline minerals. Some

[1] Professor Suess, in his "Antlitz der Erde," renders the above comparison not so fanciful as it may appear, by urging that subsidence of the crust leaves mountain-masses standing up, wherever older pillars and ridges support them, like our crypt-columns, from below. But subsidence of the surrounding areas, acting alone, will hardly account for the enormous amount of thrusting and contortion observable in great mountain-chains.

of these rocks suggest the altered material in contact with the granite of our highland (p. 199); while others are far more coarse-grained, and show large crystals of quartz and felspar. The more finely grained varieties can be split parallel to the planes along which the minerals have developed, and derive their name from the Greek σχίζω, "I cleave," being known as **Schists**. The coarser and more felspathic types are known by the old Saxon mining term, **Gneiss**.

It is obvious that their constituents have not been deposited in layers by ordinary sedimentary action. They are intergrown with one another, and here and there radiating tufts of some rod-like mineral shoot out along the layers. Mica, dark or pale, is one of the very commonest constituents, often covering whole curving surfaces of the rock; quartz occurs in streaks and elongated nodules; and little red garnets may be seen, over which the micas are folded, as if they had been pressed against an obstacle.

All these features are still more marked under the microscope, if the section is cut across the layers. Comparison with our specimens from the contact of shale and granite (p. 200) shows that we are again dealing with a secondary mineralisation. The original condition of a schist is, however, very hard to trace, owing to the complete crystallisation that has gone on in its materials. It was formerly believed that new minerals had developed along the original planes of bedding; but it appears that the schist-planes generally arise during the alteration of the mass, and obliterate any structure which it may formerly have possessed. Schists and gneisses represent, indeed, the higher stages of metamorphism (p. 199).

Slate serves well as an example of a rock in which new divisional planes have arisen under metamorphic action. The beautifully marked bedding of shale (p. 100) is due to the tiny clay particles having all become laid out with their longer axes in parallel planes, like little plates spread in layers over one another. The weight of subsequent beds presses any upstanding particles down into the requisite position, thereby assisting the delicate regularity of the stratification. The rock thus splits, almost like sheets of paper, along its planes of bedding. But if such a rock is subjected to steady pressure, acting parallel or obliquely to

the bedding-planes, the little platy particles will shift among themselves, and will finally struggle round, until their flat surfaces are perpendicular to the direction of pressure. The delicate shale-structure thus disappears, and still more marked planes of division arise in a new direction throughout the rock. We then say that it possesses a *cleavage*, which is one of the earliest features of metamorphism produced by pressure.

Again and again we can trace in slates the direction of the original bedding. Greenish bands run across the cleavage-surfaces, and are often somewhat crumpled. These represent gritty and more resisting beds, which were unable to take up the cleavage. It is clear that cleavage could be produced in an irregularly piled mass of plates, or in a sackful of pins; but it could not arise in a mass of well-rounded sand. The particles must be distinctly short in two directions and long in the third, as in the case of rod-shaped amphiboles, or long in two directions and short in the third, as in the case of flakes of mica. Grains of spherical form are obviously not forced to shift their positions in this way under pressure.

The chances are that a rock-mass, subjected to such enormous pressures as occur within the earth, will tend to become deformed, and will flow away in the direction of least resistance (compare p. 288). Usually, as we have said, a movement will be set up among the particles in directions perpendicular to that along which the pressure acts. If there is space for such movement, the more resisting particles may become fractured, and their powder may be streaked out round about them. Thus sand-grains may be converted into lens-shaped masses of powdered quartz, the principal cracks that cross the rock being parallel to the direction of pressure.[1] By this spreading out and deformation of the original grains, even a sandstone may have a rude cleavage imparted to it.

In almost every slate, chemical and mineral changes have accompanied the purely physical ones. The cleavage-surfaces become coated with delicate films of mica, and this mineral developes abundantly through the rock. But its plates can grow only in the direction of the cleavage-planes, and thus

[1] See W. J. Sollas, "On the Structure and Origin of the Quartzite Rocks in the Neighbourhood of Dublin," *Proc. Roy. Dublin Soc.*, vol. vii (1892), p. 185.

finally help to emphasise these surfaces of division. When new minerals have developed to a conspicuous extent, the rock passes into a schist. A simple slate is merely cleaved; a schist possesses a cleavage, accompanied by more or less extensive molecular changes, its older constituents becoming enlarged by the addition of new crystalline material, and new combinations occurring, giving rise to "secondary" minerals.

The mineralisation of the rock, however, destroys the perfection of the cleavage. Knots of garnet, quartz, or andalusite, needles of amphibole, and thick lens-like aggregates of mica, grow under the influence of heat and pressure, and roughen the surfaces of division. Let us picture the results of lateral movement among all these materials, whether they have already consolidated or are still developing. The rock tends to ooze outwards in directions perpendicular to that of the pressure. Every mineral aggregation becomes deformed and spreads out into a lenticle; even the quartz may yield, as we saw above, and the robust garnets may also be broken down. There will thus be a true flow of the crystalline materials, the micas especially being carried along in sheets over the more knotty and irregular constituents. Silvery mica becomes, in fact, often plastered on to the surfaces of every other mineral, and assumes an exaggerated importance until we break the rock across the cleavage-planes. These planes are so wavy and irregular, so modified by the flow of the mixed materials, that we cease to speak of "cleavage" in a schist; we say that the rock possesses **foliation**. The "folia" which give rise to this structure are the deformed and flattened minerals, their typical shape being that of greatly extended double-convex lenses, often bent and crumpled. The thickest portion of any one may be taken to represent the region where the crystal or crystal-group first began to develope in the rock.

After what we saw of contact-metamorphism (p. 199), we shall not be surprised at the variety of minerals that arise during these larger processes. Felspar granules are common, and form a sort of mosaic in certain layers; and long needles of green hornblende, or of various silicates rich in alumina, spread along the planes of foliation. There is a complete passage between slate and schist, and between schist and certain types of gneiss, and the one rock may have arisen from the other by long-continued metamorphism.

But it is only rarely that crystalline schists can be traced in the field into the sedimentary rocks which provided their materials. The folding and faulting of the whole rock-masses have been so enormous that all continuity between the original unaltered sediment and the metamorphic product is likely to have been broken through. Moreover, schists very commonly arise from the metamorphism of igneous masses, in which a number of minerals are present ready-formed, serving as centres for new products to gather round. Thus gabbros and diabases have been traced into hornblende-schists. The pyroxene breaks down and recrystallises as granular hornblende; the plagioclases become reconstituted in fine-grained and similarly granular groups; and the flow of the rock under pressure draws out these minerals into distinct foliated bands. Every feature of the flow-structure of molten lava (p. 165) is imitated by the movement of these crystalline and practically solid materials. The larger crystals of the original rock often escape complete destruction, and appear as elongated knots or "eyes," disturbing the regularity of the foliation.

Similarly, a great proportion of the gneisses result from earth-pressures acting on granites and their allies. The rock breaks down[1] and begins to flow; the quartz in part becomes powdered, and the larger grains are cracked and elongated; the felspars are similarly broken and deformed; and a foliation is given to the mass by the mica or other yielding silicate, which forms films and wavy streaks in among the other minerals. Many gneisses, on the other hand, merely show the original flow of the molten rock (p. 212), particularly where the mass was intruded after a certain amount of separation had gone on among its constituents.[2] In other cases the intrusion of parallel igneous sheets along the divisional planes of some crystalline rock has given rise to a coarse gneissic structure, the bands of the original rock alternating with those formed by its invader. But, in a great number of gneisses there is clear evidence of the influence of pressure-metamorphism. The varieties of schist and gneiss need in no way surprise us, when we picture the variety of materials brought by subsidence into the hotter regions of the earth's crust, and there subjected to compression in some directions

[1] Compare T. G. Bonney, "Biotite and Hornblende from the Binnenthal," *Quart. Journ. Geol. Soc.*, vol. xlix, p. 112.

[2] Geikie and Teall, *Quart. Journ. Geol. Soc.*, vol. l (1894), p. 657.

and to extension in others, like a red-hot iron bar between the rollers of a factory.

Some gneisses possess a most marked banded structure, with sheets of quartz and pink felspar folded in among darker and finely grained micaceous layers. Such cases probably result from the metamorphism and rolling out of a region where an igneous rock had penetrated a mass of clays; our old granite highland may thus some day become kneaded up again in the great earth-mill, and only a general streakiness in the resulting gneiss will show the original complexity of its structure.

Clays and shales and slates give rise to **Mica-schists**, containing varying amounts of quartz and garnet, and perhaps a little felspar, according to their original chemical constitution; but highly siliceous sediments produce **Quartzites**. Quartzite is the hardest rock ordinarily met with; it breaks across the original sand-grains, and furnishes very angular fragments highly suitable for road-metal. Sometimes its granular character can be seen with a lens, a cement of secondary silica having bound the whole together. This cement is deposited in perfect crystalline continuity with the grain round which it is formed, and the quartz-coatings of any two grains meet one another in the space between them and interlock completely with one another. Hence the rock, with the exception of the few impurities that it may have contained, becomes a mass of quartz throughout, and the knife can no longer produce any impression on it. **Quartz-schist** results from the deformation of such a rock, as already described (p. 299); and the foliation is often aided by flakes of mica which were originally present, or which have developed from the impurities during metamorphism.

Limestones, again, become converted by pressure-metamorphism into **Crystalline Marbles**, all traces of their fossils, and often of their original bedding, having disappeared, and the rock becoming a mass of closely fitting granules of calcite. Streaks of materials which were subsequently carried through them by permeating waters often give marbles additional value as ornamental stones. Where a flow has occurred under pressure, any impurities present, or capable of producing crystals, commonly mark out the foliation-planes; and thus we have micaceous marbles, which are common in the south-west regions of the Alps, and marbles with amphi-

bole, developed in spreading fern-like patches, such as those of central Sutherland. Such foliated marbles may well be described by the old French name, **Calcschist**. In metamorphosed limestones, the softness of the calcite, and its glancing cleavage-surfaces, will easily serve to distinguish the rock from quartzite.

Crystalline Dolomites also occur, where a limestone has been chemically altered, half of its molecules of calcium carbonate having been replaced by magnesium carbonate, and the mass having then been subjected to pressure-metamorphism. The specific gravity of such rocks is about 2.85, a character that will distinguish them from ordinary marbles, which give about 2.72. True dolomite, moreover, where the replacement has been in the proportion stated above, does not effervesce in cold acid, like ordinary limestone, but only upon heating (p. 18).

Schists sometimes consist of hornblende and granular felspar in foliation-layers (*Hornblende-schist*), as at the Lizard in the south of Cornwall. These, as above hinted, are the products of the metamorphism of igneous rocks of the "greenstone" or diabase type (p. 208). *Chlorite-schists*, commonly spotted with magnetite, probably also result from the alteration of igneous rocks; and *Serpentine-schists* are fairly common among the Alpine ridges, these soft and easily squeezed masses arising from the metamorphism of rocks once rich in olivine.

As we go up towards the St. Gotthard Pass by the steep-sided valley of the Reuss, the walls begin to close in, and the rocks around us become more coarsely crystalline. At Göschenen, where we look up towards snows and glaciers near at hand, the bare cliffs of the ravine are formed of a white micaceous granite, passing, by development of foliation, into gneiss. This is the typical rock of the central Alps, and is traversed by huge joint-planes, which often give smooth surfaces to the cliffs. The most striking part of the valley is between Göschenen and Andermatt, after the great railway-tunnel has started beneath us on its nine-mile journey through the ridge. An avalanche-gallery protects us from the slip of the great jointed blocks of granite, and the road winds upward in characteristic Alpine curves. The Reuss comes down in thunder beneath the Devil's Bridge, deluging the road with spray; and the solid promontory in front has been bored

through to provide a passage. Suddenly, on the other side of it, we emerge upon a long grassy valley, leading westward to the Furka Pass. The hills on either side, often snow-covered, are smooth, and green with vegetation; and the châlets of Andermatt lie smiling in the entrance of the valley, with the ruined tower of Hospenthal upon its little mound beyond.

We are reminded of the clustering of the villages along certain valleys in the Juras; and we have, in fact, now come across, 4800 feet above the sea, one of the remaining infolds of Mesozoic strata in a deep synclinal of the schists.

In the grey limestones before Andermatt, corals and sea-lilies have been found, and the calcschists extending up to Hospenthal contain Lower Jurassic belemnites.[1] Similar remains, crushed and broken, with unmistakable fragments of ammonites, occur on the much frequented pass of the Great Scheidegg near Grindelwald, and in numerous other places. Above the Great Scheidegg towers the crag of the Wetterhorn, in which Jurassic synclinals lie almost horizontally amid the intense folding of the gneiss. The metamorphism of the Mesozoic rocks has often proceeded so far as to convert them into mica-schists, in which all trace of fossils is obliterated.

And now from Hospenthal, probably in cold drifts of northern cloud, we turn out of this strange high valley towards the sterner masses on the south side of the synclinal. With windings at first, and then one final bend, the road is carried up the flank of a hollow five miles long, a typical and desolate upland of the Alps. The summit of the St. Gotthard Pass, 6936 feet above the sea, is a little plateau in the granite, with a floor of beautifully glaciated rocks. A few chill lakelets lie in the hollows, and already denudation has broken away many of the ice-worn surfaces upon their margins.

Here we are, then, upon the central Alpine ridge, the great crystalline core which often rises 13000 and 14000 feet above the sea, reaching 15730 feet in its south-west prolongation at Mont Blanc. The rocks that compose it are exposed, broadly speaking, over an area 550 miles (900 km.) long by 40 miles (70 km.) wide;[2] but the frequent infolds

[1] C. Schmidt, in the "Livret-guide géologique dans le Jura et les Alpes," 1894, p. 151.

[2] See Noë's admirable "Geologische Übersichtskarte der Alpen" (Ed. Hölzel's geographisches Institut, Vienna).

of far younger masses show how much had to be worn away before the core was thus revealed. Pebbles of Alpine gneiss and granite occur in the Mesozoic and Cainozoic beds; and hence we know that a great part of these crystalline rocks existed, like our imaginary cathedral-floor (p. 296), beneath the sheets of the sedimentary rocks which have since been crumpled with them. The Miocene conglomerates at St. Gallen contain few pebbles from the central gneiss, and vast quantities from the former coating of Mesozoic limestones. Moreover, specimens of rocks known only near Lugano, on the south side of the present chain, occur in these northern pebble-beds; while great erratic blocks lie in the more recent surface-deposits of St. Gallen, which have similarly come from south of the now lofty Tödi range. Hence Swiss geologists believe that, in Miocene and even later times, the high ridge lay farther south than now, and that the central folds of the St. Gotthard and the Bernese Oberland have been subsequently upheaved. Such simple observations bring before us a tremendous picture of the great wave in the earth's crust, travelling from south to north, forcing the Mesozoic beds into enormous folds, and finally crumpling up even the Miocene conglomerates, until it died down against the old massive rocks of southern Germany.

Whatever, then, may be the age of the rocks forming the central core of the Alps, they owe their present elevated position to earth-movements which culminated at the close of Miocene times. From our crest of vantage, we may perhaps now make a general survey of the matter. The Alps, as we know them, are later than the humbler Juras, which already formed a chain of island-peaks at the end of the Lower Cretaceous epoch. The sea lay over Switzerland in Eocene times, and extended away across Egypt in the east. The Oligocene period opened with an uplifting movement, which drove the sea back from Lausanne and central Switzerland, but left an inlet on the west reaching up to Bâle; and this movement continued into the Miocene period, giving us again fresh-water deposits. Then the sea temporarily returned, spreading from Bâle and Berne round the Juras, and up the valley of the Rhône, while the central Alps still continued to heave themselves slowly above it, contorting the Mesozoic strata and sending down showers of pebbles along the beds of their rapid streams. The rising axis shifted

northward, as we have above described, and the whole Alpine lands became dry at the end of the Miocene period, the Pliocene being merely represented, as at Dôle, by river-gravels and alluviums.

The form of the great Alpine axis, raised under the influence of pressure from the south-east and south, was moulded, like that of the Juras, against older masses; and the range, running from the south of Turin nearly to Vienna, is merely part of a great system of mountain-chains, all intimately connected, and all of the same comparatively recent age.[1]

Even the old crystalline rocks of the core, in the stress of this period of upheaval, have actually renewed their youth. Dr. Lawson[2] showed in 1888 how the oldest gneisses of Canada had become in part remelted at a later period, and had flowed like igneous masses into the cracks of the overlying beds. This gives us the other end of the circle of events, by which a granitic rock may become converted by pressure and movement into a gneiss. Here it has gone back into the granitic condition, and it becomes impossible to style it, in this form, one of the oldest rocks of the district. In its consolidated igneous offshoots, we are bound to say that it is later than the beds into which it has intruded. Similar igneous gneisses have now been observed by M. Michel Lévy in the central masses of Mont Blanc.[3] The coarse gneiss, often well foliated, of which the magnificent walls and *aiguilles* are composed, has been shown to be an intrusive mass, instead of the oldest rock in the core of an anticlinal. Down below, this gneiss may be connected with the ancient floor of Europe; but it is undoubtedly, in its present position, younger than the adjoining schists, and its foliation is in part due to the inclusion of foreign schistose material as it flowed (compare p. 301).

Dr. J. W. Gregory[4] has similarly referred some of the gneisses of the Cottian Alps to a very recent date. He describes several intrusive junctions, and regards the

[1] See Suess, "Antlitz der Erde," Band i. p. 303.

[2] "Geology of the Rainy Lake Region," *Geol. Surv. of Canada, Annual Report for* 1887.

[3] See section in De Lapparent, "Traité de Géologie," 4me. édit., p. 1772, and Duparc and Mrazec, "Massif du Mont Blanc," *Mem. Soc. Phys. et d'Hist. Nat. de Genève*, t. xxxiii (1898).

[4] "The Waldensian Gneisses and their place in the Cottian Sequence," *Quart. Journ. Geol. Soc.*, vol. l. (1894), p. 232.

foliation as a flow-structure, finding that it is parallel to the walls of the dyke-like offshoots. "The dykes," he writes, "often have an irregular course through the schists, but the foliation in them remains quite independent of the surrounding rocks." Instead of treating this gneissic granite as an Archæan mass, as so many authors have done, Dr. Gregory is driven to this conclusion:—"Paradoxical though it may appear, the evidence renders it most probable that the Waldensian gneiss, instead of being of Laurentian[1] age, is really Pliocene, and, with the exception of the Saharian and recent alluvium and the glacial moraines, is the newest rock in the Cottians."

The reasonable idea that schist and gneiss may be manufactured in any period of the earth's history was familiarly held by many of the older geologists. The most important discovery of recent times with regard to metamorphic rocks is that the planes of foliation have often nothing to do with the original stratification of a sediment; and this fact has made it more difficult to assign a sedimentary origin to this or that group of schists. But the alterations in an obvious shale when in contact with a granite mass are of a sufficiently convincing character; mica-schists and andalusite-schists are in such cases produced, as it were, before our eyes. It is not difficult, then, to believe that great thicknesses of schist have been added to the crystalline series of the Alps, even during the latest movements of the chain. Such movements allowed of the intrusion of gabbros and basalts, which became rolled out into sheets of hornblendic and chloritic schists, and of granites, which, flowing in under pressure, filled up some of the great mountain-domes with gneiss.

The crystalline core, then, on which we stand at the summit of the St. Gotthard Pass is a complex mass of various ages, representing the kneading together of many rocks in the earth's mill.[2] Let us now descend on the southern side towards the Italian plain.

[1] Early Archæan.

[2] One of the clearest discussions of the problems of pressure-metamorphism occurs in Professor Lapworth's "Intermediate Text-Book of Geology" (1899) pp. 124–147. The effects, on the other hand, of contact-metamorphism on a large scale, and of the interpenetration of sediments by granite-magmas, are well maintained by Lévy, Lacroix, Duparc, and other French authors.

The first wonderful curvings of the road, which is buttressed up tier upon tier in the steep head of the Val Tremola, bring us across slabs and joint-surfaces of gneissic granite, like those of the gorge at the Devil's Bridge. Then, in the valley and in the succeeding green and open country, set with little woods and rough grassy hollows, we meet exposures of fine-grained mica-schists. We have crossed the great central fan-fold of the gneiss, and are among the synclinals and anticlinals which lead up to it from the south. The next series of schists, rich in lime in one combination or another, are referred by the Swiss geologists to the Jurassic system. They occupy the same position as those with crushed and elongated belemnites on the passes east and west of us.[1]

At the mouth of the grim Val Tremola, veins of a kind of gneiss, occurring in the schists, suggest that here also we have evidence of the rolling out of an igneous contact-zone. These older schists are beautifully foliated, passing into gneiss; but the far newer rocks of the Jurassic zone also consist of a great variety of schists. Though we find here in association masses of very different ages, we can understand how older observers thought they saw a complete passage from unaltered sediments to crystalline granite, as they went from the exterior to the interior of a mountain-chain. And even now the central masses of the Alps may prove to have the most recent origin.

Airolo, of Italian aspect, stands upon this southern infold of Mesozoic schists; one or two other synclinals are caught in, and are exposed on the walls of the great valley; and then we have a long stretch of somewhat fine-grained gneisses, extending right away to Bellinzona. Here the rivers from the north have formed a broad alluvial flat, which is still occasionally flooded. The rainfall can now no longer deepen the valleys, and we see in this spreading of the alluvium, creeping back towards the central range, a model of those larger processes that have produced the Italian plain. A little farther down, we come into the southern lake-country, which repeats the features of northern Switzerland. The elongated winding forms of the "Italian lakes"

[1] This view of the age of the altered limestones and other rocks in this region of the Alps is not uniformly accepted. See Bonney, *Quart. Journ. Geol. Soc.*, vol. xlvi. (1890), p. 187; vol. l. (1894), p. 285, and vol. liii. (1897), p. 16.

are easily seen on any map. The Lago Maggiore, thirty-five miles long and two miles wide, is clearly the flooded valley of the Ticino; at Pallanza, the mouth of the Toce forms the one conspicuous side-inlet. But no ordinary alluvial dam has closed the outlet at the southern end; the whole valley-floor must have become curved downwards, giving rise to this lake 2800 feet in depth. At present it is partly filling up again, and Locarno, at the northern end, stands upon a delta of the most exquisitely developed form.

If we follow the route of the St. Gotthard railway to Lugano, we find another group of warped and tilted valleys. The Lake of Lugano consists of at least four valleys, and its original drainage-lines are difficult to trace. At present it overflows from a western arm into the middle of the Lago Maggiore. The three-armed Lake of Como presents fewer difficulties; from north to south, from Chiavenna to Lecco, it forms a fine and gently curving valley; and another stream formerly entered this obliquely, from the watershed in the neighbourhood of Como. It is certainly unusual for a tributary to point so distinctly up the valley of the main stream; but there are local examples of this in the unsubmerged valleys immediately to the north.

From the Triassic beds of Lugano we can pass to the Jurassic of Como, and so to the Cretaceous exposures about Lecco. Here even the Eocene sea has left us traces, full of nummulites, like those of the northern flank of the Alps. But the plain of Italy has covered up most of the Mesozoic and Cainozoic beds, and we have to go eastward to find the counterpart of the boldly scarped limestone ridges, which form the Alpine foot-hills across central Switzerland.

In among the glacial detritus west of Como, there lie patches of marl, containing marine Pliocene fossils. It is perfectly possible, and indeed probable, that glaciers descended from the central ridge, which was then at its full height, and mingled their terminal moraines with the deposits of an Italian sea. In any case, the huge earth-wave of the Alps rose up, without driving back the sea on the south side. Shallowings had occurred in the Italian region in early Miocene times, but were followed by renewed deepening of the sea along its northern shore; parts of the **Apennines** may have risen in the Oligocene and Miocene periods, but their main upheaval actually occurred at the con-

clusion of the Pliocene. The marine Lower Pliocene series lies upon the Apennine slopes, and the active volcanoes of western and southern Italy are fair evidence that earth-movement is still in progress. The granite core of the Apennines is exposed only at its northern and southern ends, through the mantle of Cretaceous and Jurassic strata. We seem to be carried back, in viewing this modern mountain-range, to the Alps of Miocene times, before their final crumplings and upheavals had taken place. The highest point of the Italian range is Monte Corno in Abruzzo, 9521 feet above the sea; and there is no good reason to believe that these ridges have ceased growing at the present time. Such growth, however, cannot be accomplished without considerable reduction in the width of the masses which lie at present above sea-level, since Professor Heim[1] computes that the Alps in some parts occupy only half the horizontal space formerly required by the sediments that were used up in their construction.

If it seems extraordinary that the Apennines should practically be of Post-Pliocene origin, and that all the complex peaks and gorges of the Alps should have been carved out in them since Miocene times, we have only to turn to other mountain-chains to verify these conclusions. The principles that guided William Smith cannot here deceive us. Nummulitic strata are found infolded with the **Pyrenees**, a range that reared itself in Eocene and early Oligocene times. The **Juras**, as we have seen, were not clear from the sea until the Miocene period, and are thus somewhat younger than the Pyrenees and older than the Alpine foot-hills.

The **Himálayas** are later than the Cretaceous period, and their principal folding occurred between Miocene and Pliocene times;[2] but there is evidence, from the disturbance of the Pliocene strata on their flanks, that they continued to rise even later, and it is probable that they are still in upward motion.

The **Rocky Mountains**, again, are of Eocene and later age, the western ridges being Pliocene, and younger than the

[1] "Mechanismus der Gebirgsbildung," Band ii, p. 213.

[2] Griesbach, *Mem. Geol. Survey of India*, vol. xxiii, p. 47; Blanford, Medlicott, and Oldham, "Manual of the Geology of India," 2nd edit., pp. 467–487.

eastern plateaux. We have already (p. 116) referred to the Post-Pliocene movements of the continental coast in California; and it is equally instructive to realise that the cañon of the Colorado River, 6200 feet in depth, has been excavated since early Pliocene times.

Even the great chain of the **Andes**, which is increased locally by volcanic cones, is younger than the middle of the Cretaceous period.

Wherever, in fact, we study high mountain-ranges, we find them to be of comparatively recent origin. The supremacy of the Himálayas, attaining 29000 feet, is only secured to them by their youth. The older ranges become worn down by denudation, like those of Norway, or, still more strikingly, like those of our Scottish highlands and of Wales. If we have lost our boldest mountain-chains, which once fronted the western ocean in the lordly fashion of the Andes, we can at least learn something from their bare and dissected remnants. The folds have been worn down, and it is difficult now to point to the position of the central ridge; but in the west of Sutherland and Ross-shire the phenomena of the overthrusting of more recent sediments by crystalline rocks are displayed, as they might be on the flank of any modern mountain-chain. In the foothills of the Alps, the huge folds and thrust-planes can be traced out on thousands of feet of precipitous rock; but it is a still more difficult matter to follow out the succession of events in our own highlands, where only little flecks and patches of some of the largest folds remain. Professor Nicol was the first to bring the study of modern mountains to bear upon the Silurian range of Scotland; but the proof of the general correctness of his views was left to the detailed mapping of Professor Lapworth, nearly thirty years later. Professor Lapworth[1] showed how thrust after thrust had piled up the strata in the Durness district, so that what had long been regarded as a regular and conformable succession of deposits was proved to be a repeated and often an inverted series. His work was extended by the officers of the Geological Survey,[2] who showed again and again that Archæan gneiss overlay little altered Cambrian and Ordovician strata.

[1] "The Secret of the Highlands," *Geol. Mag.*, 1883, pp. 120, 193, and 337.

[2] "Report on Recent Work in the North-West Highlands of Scotland," *Quart. Journ. Geol. Soc.*, vol. xliv (1888), p. 378; see especially figs. 8–22.

The old continental edge, represented by Norway, the west of Sutherland, and the outer Hebrides, is continued south into the counties of Donegal and Mayo. Here, however, the oldest gneiss is hidden; and the highlands are formed of an ancient schistose and crumpled series, penetrated by granite which has become gneissic during flow.

Gneisses and schists have now a new meaning for us, and open up some of the most tremendous problems of the structure and history of the earth's crust. While some of these rocks represent the flow of deep-seated and once molten masses, which, although in motion, had become in great part crystalline, others tell us of the fracture and movement of rocks already firm and hard. The folds that we see upon the coast of Devon or Dorset (Plate XI), with their contortions and actual reversals of unaltered strata, show how much movement may go forward without metamorphism of the rocks. But down below us, and in the heart of an uprising mountain-chain, the greater heat and pressure may be manufacturing schists at the present day. The Pyrenees, the Western Alps, and the Karpathians, have probably already come to rest. Where will the next range rise to take their place, when they have become reduced to denuded remnants?

The Pliocene or Post-Pliocene elevation of two axes, at least, gives us some fair ground for speculation. The Apennines have already started with considerable success (p. 309); but the Wealden anticlinal (p. 282) still remains only some 300 to 800 feet above the sea. The Eocene and Oligocene rocks have been denuded back upon its flanks, the Cretaceous fold has been cut through, and near Hastings the Purbeck beds have been brought up and bared upon the surface.[1] So far it is mere guess-work to suggest anything more serious for the future; but there are signs of the formation of small subsidiary folds within the main limbs of the Wealden anticlinal. Perhaps, after all, the gneiss and granite far below will once more see the light of day; London and Brighton, long before lost to human knowledge, and buried in conglomerates from the rising mountain-chain, will become infolded in the recumbent synclinals of the foot-hills, north and

[1] Compare Strahan on Dorsetshire, *Quart. Journ. Geol. Soc.*, vol. li. (1895), p. 549.

south; and, finally, crowds of regenerate mortals, each one a scientific observer from his birth, will flock on public holidays to the snow-peaks of the English Alps.

And so the folds of the mountains have brought us back to our own islands, to Sutherland and Mayo, to Dorset and the Surrey hills. Our first observations on the form of mountain-slopes (p. 28) have led us on and on, until we have halted on the border of some of the most mysterious problems of the earth. Though we travel, as geologists should, from one country to another, we may rest assured that these isles of ours contain ample matter for research. Whether we cycle along the great through-routes, noting scarp after scarp, the Chilterns, the Cotteswolds, Wenlock Edge, until we reach the mountain-land of Wales, or whether we walk in an afternoon across the open fields around our homes, the subject of our studies is always near us, the material is ready to our hands. And if we have journeyed thus far pleasantly together, it is perhaps time that we should now choose our own work, and our own way of setting about it.

"And so, without more circumstance at all,
I hold it fit that we shake hands, and part."

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